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WADC TECHNICAL REPORT 53-373

SUPPLEMENT 6

A00229675

DEC 23 '58

A REVIEW OF THE AIR FORCE MATERIALS RESEARCH AND DEVELOPMENT PROGRAM

Helen H. Maxwell

Materials Laboratory

NOVEMBER 1959

Statement A
Approved for Public Release

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WRIGHT AIR DEVELOPMENT CENTER

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WADC TECHNICAL REPORT 53-373
SUPPLEMENT 6

A REVIEW OF THE AIR FORCE MATERIALS RESEARCH AND DEVELOPMENT PROGRAM

Helen H. Maxwell

Materials Laboratory

NOVEMBER 1959

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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ADHESIVES, STRUCTURAL

WADC TR 56-533 Pt II
ASTIA Document No. AD 155806

August 1958

SUBJECT: ELEVATED TEMPERATURE RESISTANT SILICONE STRUCTURAL
ADHESIVES FOR METALS
INVESTIGATOR: Beverly B. Stewart
Frank J. Riel
Samuel E. Susman
CONTRACT: AF 33(616)-5141
CONTRACTOR: Narmco Industries, Inc.
ABSTRACT: This report describes research and development under
Contract AF 33(616)-5141, "Elevated Temperature Resistant Silicone
Structural Adhesives for Metals" during the period 15 March 1957 to
15 May 1958.

The first objective of this program was the synthesis and evaluation of carboxyphenyl polysiloxanes. Several polymers, which contained varying percentages of carboxyphenyl groups, were prepared and evaluated as adhesives. It was observed that those resins containing carboxyphenyl groups had slightly lower bond strength compared to control resins. Failure of all polysiloxane bonds was primarily cohesive failure indicative of weak polymer structure.

The second program objective was the development of polymer structures, other than simple polysiloxanes, made from silane and siloxane monomers. A bisphenol silane was synthesized, and phenolic and epoxy resins derived from it were evaluated as metal-to-metal adhesives. Synthesis of several intermediates required for hydroxyphenyldisiloxane synthesis was accomplished; preparations of two hydroxyphenyldisiloxanes were carried out.

Three types of siloxane resins derived from Bisphenol-A and ethoxysiloxane monomers were examined. One type of siloxane-phenolic and a polysiloxane resin were found to have excellent heat resistance. Various combinations of these resins were compounded with conventional epoxy and phenolic resins, and evaluated as metal-to-metal adhesives.

Manuscript released by author July 1959 for publication as a WADC Technical Report.

WADC TR 53-373 Sup 6

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November 1958

SUBJECT: EVALUATION OF STRUCTURAL METAL BONDING ADHESIVES
FOR BONDING GLASS-FABRIC LAMINATES TO METALS

INVESTIGATOR: H. W. Eickner

CONTRACT: DO 33(616)-58-1

CONTRACTOR: Forest Products Laboratory

ABSTRACT: An investigation was made by bonding lap-joint panels of glass-fabric laminates to aluminum alloy and to stainless steel with nine structural metal-bonding adhesives to determine if these adhesives were also suitable for this type of bonding. Test data were obtained on the aluminum-plastic bonds at -67°F., at 70° to 80°F., at 350°F., and after a 30-day exposure to salt water spray. The stainless steel-to-plastic bonds were tested at 70° to 80°F., at 350°F., and at 500°F. Laminates prepared with four representative types of resins were included in this research.

Lap-joint strength values generally averaged from 2,000 to 2,500 pounds per square inch at -67°F., at 70° to 80°F., and after 30 days exposure to salt water spray. However, at 180°F some of the adhesives started to lose strength, and, in tests at 350° and 500°F, only the strength values of the more heat-resistant adhesives exceeded 650 pounds per square inch. Strengths at the higher temperatures were generally better on the plastic laminates prepared with heat-resistant resins. The results indicated that a number of adhesives, as presently formulated to qualify for structural bonding of metals, will adequately bond glass-fabric laminates to metals. No special requirement or specification is required, therefore, for adhesives for this type of bonding, other than the existing specifications on metal-bonding adhesives.

BERYLLIUM

WADC TR 58-457 Pt I
ASTIA Document No. AD 208662
OTS Release

February 1959

SUBJECT: RESEARCH ON TECHNIQUES FOR THE PRODUCTION OF ULTRA-PURE BERYLLIUM

INVESTIGATOR: Joseph L. Lukesh Henry S. Spacil
Malcolm Basche Laurence McD. Schetky
CONTRACT: AF 33(616)-5300
CONTRACTOR: Alloyd Research Corporation
ABSTRACT: The brittleness problem of beryllium is described and the empirical and theoretical approaches to its solution discussed. The Alloyd Research Corporation program for the production of very high purity beryllium is described in detail. Experimental results are outlined, conclusions are drawn, and recommendations for future work presented.

WADC TR 58-478 Pt I
ASTIA Document No. AD 208663
OTS Release

February 1959

SUBJECT: DEVELOPMENT OF WROUGHT BERYLLIUM ALLOYS OF IMPROVED PROPERTIES
INVESTIGATOR: John G. Klein
Leslie M. Perelman
Wallace W. Beaver
CONTRACT: DO 33(616)-57-19
CONTRACTOR: The Brush Beryllium Company
ABSTRACT: A review of the literature on alloying and other structural modifications and their effect on mechanical properties of beryllium is included in this report.

Primary consideration is given to mechanical and physical properties of QMV beryllium, both sintered and wrought, beryllium-rich alloys, and structurally modified metal; fabrication procedures are described.

A discussion of background and methods used to study preferred crystallographic orientation in wrought beryllium is appended.

BIOCHEMISTRY

WADC TR 56-384 Pt II
ASTIA Document No. AD 155857
OTS Release

August 1958

SUBJECT: AN EVALUATION OF FUNGICIDAL TREATMENTS IN COTTON
CARGO PARACHUTE WEBBINGS STORED AT COLLEGE, ALASKA

WADC TR 53-373 Sup 6

INVESTIGATION: Emma F. Little

ABSTRACT: Fungicidal formulations with water repellents and without water repellants were applied to four types of cotton cargo parachute webbings made to Specification MIL-W-5665A. Three of the formulations contained copper 8-quinolinolate and the fourth contained dihydroxy-dichloro-diphenyl methane.

Treated and untreated webbings as received from the manufacturer, and warp threads from these original webbings, were tested for initial breaking strength at Wright Air Development Center prior to storage. These breaking strengths were used as the control data for the materials stored for periods of 4, 8, and 12 months at College, Alaska. Threads from stored webbings were broken to detect any losses in breaking strength due to tendering by the fungicidal treatments. After periodic shelf storage, the webbings were evaluated for fungus resistance. The fungi used as test organisms were Aspergillus terreus, Myrothecium verrucaria and Chaetomium globosum. Visual examinations were made after fungus resistance evaluations, and breaking strength data were derived from threads from webbings after storage and after fungus resistance investigations. A statistical analysis was made of these data. Any losses in fungicide efficiency were determined from the data showing the differences in breaking strength retention of the exposed threads when compared to the original controls.

All formulations of copper 8-quinolinolate, except Formulation B, evaluated in this research were satisfactory fungicidal treatments in cotton cargo parachute webbings, Specification MIL-W-5665C, providing the minimum metallic copper content as copper 8-quinolinolate was 0.14% by dry weight of the treated material. On this basis, the minimum amount of copper 8-quinolinolate required to give adequate fungus resistance was 0.83% by dry weight of the treated material. The formulation of dihydroxy-dichloro-diphenyl methane was equally acceptable for USAF use providing the minimum fungicide content was 0.9% by dry weight of the treated material. Water repellents added to the basic fungicidal formulations, slightly improved the overall fungus resistance of the treated webbings. The phthalocyanin dye used for Type XV webbing was not compatible with any of the fungicidal formulations. Untreated webbing containing this dye was badly discolored and tacky. Mineral dye was compatible with all materials.

WADC TR 57-366
ASTIA Document No. AD 155686
OTS Release

June 1958

SUBJECT: EVALUATION OF FUNGICIDAL VINYL COATED COTTON DUCK
INVESTIGATOR: Jacob K. Frederick, Jr.
Robert E. Otto, 1/Lt., USAF
David H. Pfister
CONTRACT: AF 33(616)-3929
CONTRACTOR: Lowell Technological Institute Research Foundation
ABSTRACT: This investigation was concerned with determining the effect of shelf storage or outdoor exposure for periods of four, six, ten, and twelve months followed by soil burial for two weeks upon the breaking and tearing strengths, low temperature flexibility, gasoline resistance, hydrostatic pressure resistance, weathering resistance, high temperature blocking, and color of 8.0 ounce vinyl coated cotton duck containing in the fabric or in the coating various fungicides. In addition to the fungicides, some of the fabrics contained a stabilizer designed to prevent light deterioration. The exposure sites were in Alaska, Florida, New Mexico, and Ohio. The fungicides utilized in these studies were copper hydroxynaphthate (CuOHN₂ph), copper 8-quinolinolate (Cu-8-Q), dehydroabietylammmonium-pentachlorophenoxide (DAAP), dodecyldimethy-benzyl-ammonium-cyclopentane-carboxylate (DDBACC), and dihydroxydichloro-diphenyl-methane (3DM). The factors of breaking and tearing strength were considered to be of primary importance, while the others were considered as of secondary importance.

The primary factors were subjected to an analysis of variance and an analysis of covariance. The analyses considered main effects of fabric direction, exposure time, sites, and fabrics, and the interactions of fabric direction and time, fabric direction and sites, fabric direction and fabrics, time and sites, time and fabrics, and sites and time.

In addition, differences between fabrics were ranked by using the Duncan Test.

The secondary factors were evaluated by ranking and by examination techniques rather than by any formal statistical tests.

The major conclusions derived were as follows:

1. Fungicides studied had no effect in preventing deterioration prior to soil burial. In soil burial, Cu-8-Q, CuOHNaph, and DDBACC supplied significantly better protection against strength loss than did DAAP and 3DM.

2. The duration of exposure had a significant effect on the loss in strength of fabrics subjected to outdoor exposure, but had no effect on fabrics subjected to shelf storage only.

3. The presence of a stabilizer had no significant effect on the prevention of strength deterioration as compared to similar fabrics not containing such a stabilizer.

4. Light can have a significant effect on strength loss, with a direct and linear relationship existing between increasing light energy and increasing strength loss.

5. The fabrics treated with the fungicides providing best protection against soil burial strength loss also showed the least harm in the low temperature flexibility test.

6. Hydrostatic pressure resistance was not adversely affected by sites, time of exposure, nor types of exposure.

7. Color had a bearing on gasoline resistance as did fungicides. Yellow fabrics and all fabrics treated with 3DM showed more deterioration than the other fabrics.

8. The chemical analyses for residual fungicide content, showed considerably less than was stated to be present for all the fungicides except CuOHNaph.

WADC TR 57-711
ASTIA Document No. AD 151127
OTS Release

April 1958

SUBJECT: EVALUATION OF FUNGICIDAL TREATMENTS FOR COTTON FABRICS
INVESTIGATOR: Joseph J. Moder
Charles W. Stuckey
CONTRACT: AF 33(616)-3867
CONTRACTOR: Georgia Institute of Technology
ABSTRACT: Separate rolls of cotton sateen fabric were treated with seven different fungicidal formulations, each formulation being applied at three concentration levels, both with or without water repellents. Six of the fungicide formulations contained copper 8-quinolinolate and one contained dehydroabietyl ammonium pentachlorophenate.

In order to determine the effectiveness of these treatments, and also to obtain information for use in designing future evaluation and acceptance tests, cloth breaking strength measurements and visual observations were made on specimens of fabric treated as follows: (1) original fabrics, (2) fabrics stored indoors on shelves or hung in a laboratory, and (3) fabrics exposed outdoors. The original fabrics were tested before and after soil burial and agar plate exposure, while only the latter was used on the other test specimens cited in (2) and (3).

For the original fabrics, there was about a 10% strength difference between the strongest and weakest fungicide treated fabric. All treatments prevented fungus growth on agar plate exposure; however, consid-

erable strength loss resulted from soil burial, after which the strongest fabric was almost three times as strong as the weakest fabric.

Twelve months of indoor shelf storage produced a negligible strength loss both before and after agar plate exposure for all fungicides. For open fabric panels hung in the laboratory at W-PAFB for two years, the copper 8-quinolinolate fungicides retained more than 94% of their original strength after agar plate exposure; however, the dehydroabietyl ammonium pentachlorophenate fungicide retained only 75% of its original strength.

The pattern of strength loss resulting from outdoor exposure varied among the test sites because of difference in the physical environment. A single linear equation, applicable to all test sites, was derived relating the strength retention to langley's of actinic exposure and relative humidity.

Fabrics treated with dehydroabietyl ammonium pentachlorophenate consistently had the lowest breaking strength after outdoor exposure at all sites. It is difficult to differentiate between the six copper 8-quinolinolate fungicide formulations because of the inconsistency in their behavior for the different test conditions and specimen types studied.

WADC TR 58-201
ASTIA Document No. AD 206893
OTS Release

November 1958

SUBJECT: THE EFFECT OF SOLAR RADIATION ON THE BREAKING STRENGTH OF OUTDOOR EXPOSED WEBBINGS
INVESTIGATOR: Robert A. Wilkinson
ABSTRACT: This program was to obtain data as to what degree solar radiation affected the breaking strength of webbings exposed to natural weather. Four groups of webbings were evaluated for breaking strength after being exposed to natural weather for specific time intervals encompassing one year. The exposure sites were Wright-Patterson Air Force Base, Ohio; Las Cruces, New Mexico; and College, Alaska.

Data obtained indicate that the service life of the present type of runway barriers can be increased to 180 days in areas of extremely strong sunlight and to 360 days in areas of moderate or small amounts of sunlight by either one of the following two methods:

1. By using 260 denier 17 filament, Type 300, OD color nylon yarn in the manufacture of the webbing.
2. By using Type 330 nylon yarn in the manufacture of the webbing.

October 1958

SUBJECT: DEVELOPMENT OF EFFECTIVE NON-TOXIC FLUORINATED
FUNGICIDAL FORMULATIONS FOR COTTON MATERIALS
INVESTIGATOR: Charles C. Yeager
Jay C. Chapin
CONTRACT: AF 33(616)-5322
CONTRACTOR: The Scientific Oil Compounding Co.
ABSTRACT: Methods of formulating 2,2'-dihydroxy 5,5'-difluoro-
diphenyl sulfide (DDFDS) were investigated with the purpose of developing
effective solvent soluble and water miscible formulations capable of pro-
ducing fungicidal and fungicidal-water repellent finishes for cotton
materials.

Initial investigations included studies on the solubility of the fungicide in a wide range of solvents and storage stability of the resulting concentrated solutions. It was necessary to find solvents, or mixtures of these materials, which would dissolve the greatest amount of the DDFDS and retain it in solution for prolonged periods of time under variable room temperature conditions. A combination of hexylene glycol with a mixture of hexyl and amyl alcohols was found to be the best for the solvent formulations. Di-isobutylketone was found to be the best for water emulsion formulations. Samples of a standard cotton sateen fabric were treated with many experimental formulations to determine their effectiveness against degradation caused by fungi and ultraviolet light. The DDFDS, when properly formulated, was found to be a very effective fungicide. However, the compound did decompose during extended, accelerated, artificial weathering. Various non-pigmented anti-oxidants and screening agents were evaluated to counteract this break-down but none were found to be wholly effective.

Preliminary work indicated that stabilization of the DDFDS can be accomplished with selected amine compounds. Formulations utilizing the stabilized fungicide proved promising when used in a fabric material especially those applied from an aqueous emulsion system.

March 1959

SUBJECT: NATURAL WEATHERING AND INDOOR OPEN SHELF STORAGE
EXPOSURE TESTING OF AIR FORCE FABRIC MATERIALS
INVESTIGATOR: Warren W. Smith
CONTRACT: AF 33(600)-34695
CONTRACTOR: South Florida Test Service, Inc.
ABSTRACT: Webbing and cloth specimens submitted by Wright Air
Development Center were exposed to natural direct weathering and indoor open
shelf storage environment by the South Florida Test Service, Inc. at Miami,

Florida for a period of twelve (12) months. The purpose of this project was to determine degree of degradation of the various samples during the exposure period.

Various degrees of degradation were noted on the specimens exposed to natural direct weathering however none was noted on the specimens subjected to indoor open shelf storage.

WADC TN 59-142

April 1959

SUBJECT: RESISTANCE OF MICROORGANISMS TO HIGH VACUUMS
INVESTIGATOR: Sam Bakanauskas
ABSTRACT: A study was made to determine the effect of prolonged dynamic vacuums on the viability of selected spore-forming fungi and bacteria. The microorganisms were exposed to pressures ranging from 1×10^{-5} to 5×10^{-7} mm Hg for periods of 2, 4, 8, 16 and 32 days.

Microorganisms used were: Aspergillus niger WADC 8, Aspergillus flavus WADC 26, Bacillus globigii WADC B5, Bacillus mycoides WADC B8, and Bacillus cereus WADC B6. With the exception of B. cereus WADC B6, spores of all microorganisms remained viable after 32 days exposure.

BRAZING ALLOYS

WADC TR 58-467

January 1959

ASTIA Document No. AD 207904
OTS Release

SUBJECT: BRAZING TITANIUM SANDWICH CONSTRUCTION
INVESTIGATOR: John F. Rudy
Robert M. Necheles
Harry Schwartzbart
CONTRACT: AF 33(616)-5357
CONTRACTOR: Armour Research Foundation
ABSTRACT: The purpose of this project was to study the feasibility of fabricating titanium alloy face sheet honeycomb sandwiches by brazing techniques. The program was conveniently divided into several phases: selection of face sheet alloy and brazing alloys, fabrication of sandwiches by various experimental methods, and mechanical evaluation of the resulting panels. The emphasis was placed on the second phase, fabrication processes.

WADC TR 53-373 Sup 6

The survey of possible face sheet alloys is discussed in some detail. The result of this survey was the decision to incorporate Mallory-Sharon's MST 16V-2 1/2Al for the alloy for primary consideration as the face sheet in the brazing process experimentation. In addition to the above alloy, Republic Steel's RS 140 (5Al-2 3/4 Cr-1 1/4Fe) was chosen as an alternative alloy for brazing above the beta transus (-1440°F) of the MST alloy. In making these selections consideration was given to producibility in thin-rolled sections, mechanical properties at room and elevated temperatures, and, possibly most important, the compatibility of the heat treatment cycle with the envisioned practical brazing cycle.

An evaluation of 17 brazing alloys as regards wettability, mechanical strength, oxidation resistance, and corrosion resistance resulted in the recommendation of Ag-28Cu-C.2Li and Ag-0.25Mg-0.2Ni-1Li as the best alloys for brazing titanium-cored panels at a brazing temperature of 1500°F . Ag-28Cu-0.2Li was the stronger of the two. These two alloys plus Ag-7Cu-0.2Li and Ag-30Cu-10Sn were found to be satisfactory for brazing stainless steel cored panel at 1600°F . Of these four alloys, Ag-28Cu-0.2Li and Ag-7Cu-0.2Li gave the strongest joints.

The process development phase centered around the development of a quartz lamp radiant heat brazement process. The details of the process, as used, and a discussion of suggested modifications and improvements for application of the same principles to large-production panel fabrication, are presented. Although the process development experiments were conducted with titanium alloy face sheet materials, the results are applicable to sandwich panel production in general. The primary advantages of quartz lamp radiant heat over presently used furnace retort techniques have to do with inherent rapid heating and cooling rates, good temperature uniformity and brazing time control, and general cleanliness of the heat source for atmosphere purity purposes. An itemized list of these advantages is as follows:

1. Good temperature control over a wide temperature range.
2. Control over temperature uniformity (or desired non-uniformity) by heating apparatus design.
3. A clean, portable heat source which can be placed within an atmosphere chamber, allowing rapid heating of the specimen directly. This eliminates the need for single-shot retorts as are presently used in furnace brazing.
4. Low equipment cost.
5. Adaptability to jiggling for adequate faying surface contact and for required contour (flatness or airfoil curvature).

6. Possibility for adaptation to continuous production, i. e., relative movement between heat source and panel.

The panels which were produced by the furnace retort and quartz lamp radiant heating processes were evaluated mechanically and by exposure of oxidation and salt spray environments. These evaluations provided data for process variable and material decisions.

CERAMICS

WADC TR 55-500 Pt II
ASTIA Document No. AD 203786

October 1958

SUBJECT: AN INVESTIGATION OF INFRARED TRANSMITTING MATERIALS
INVESTIGATOR: N. J. Kreidl R. A. Weidel
H. C. Hafner E. C. Letter
J. R. Hensler
CONTRACT: AF 33(616)-2769
CONTRACTOR: Bausch & Lomb Optical Co.
ABSTRACT: A limited compositional study of calcium aluminate glasses resulted in several prototype compositions which have superior handling and melting properties than those reported previously.

One of these compositions was melted successfully in a 30 lb. melt. Germanate glasses as well as several silicate glasses were studied on a limited basis.

Some mechanical and chemical property measurements of calcium aluminate glasses have been completed and are compared with conventional glasses.

An investigation of methods to inhibit surface deterioration of calcium aluminate glasses by water or water vapor has been started. Methods for eliminating the water absorption band at $2.7\text{--}3.0\mu$ were also studied.

Various methods for compacting polycrystalline materials were studied including cold pressing, hot pressing, controlled freezing and sintering. Compacts that transmit considerable infrared can be produced by these methods. Hot pressing seems the most practical method for continued study. Infrared transmitting compacts of NaCl, BaF₂ and MgO have been pro-

duced. A mathematical relationship demonstrated the high radiation losses in a compact due to scattering induced by voids.

WADC TR 55-500 Pt III
ASTIA Document No. AD 202842

October 1958

SUBJECT: INVESTIGATION OF INFRARED TRANSMITTING MATERIALS
INVESTIGATOR: Norbert J. Kreidl

Harold C. Hafner
Joseph R. Hensler
Robert A. Weidel

CONTRACT: AF 33(616)-2769

CONTRACTOR: Bausch & Lomb Optical Co.

ABSTRACT: The water absorption band at 2.7-3.0 μ in calcium aluminate glasses is undesirable so methods to eliminate it were studied. Techniques successful in silicate glasses were not applicable to the calcium aluminates. For example, D₂O added to a silicate glass batch shifted, as expected, the water absorption band to approximately 3.7 μ . A similar addition to a calcium aluminate batch produced no change in the position of the water absorption band. Techniques were developed for protecting the surfaces of calcium aluminate glasses from deterioration by water or water vapor. These glasses were "hardened" by conventional techniques. "Hardening" did not inhibit moisture attack.

The infrared transmission of typical calcium aluminate glasses changed slightly after exposure to 1×10^7 rep gamma radiation from a Co⁶⁰ source.

WADC TR 58-184
ASTIA Document No. AD 155774

August 1958

SUBJECT: A SURVEY OF THE THEORIES CONCERNING CERAMIC TO METAL ADHERENCE

INVESTIGATOR: A. E. Eagles, A/2c

ABSTRACT: Various theories have been offered as to the mechanism of ceramic coating to metal bonding. To date, however, no one theory has proved to explain the phenomenon adequately. This report reviews the literature pertinent to the subject.

WADC TR 58-275 Pt I
ASTIA Document No. AD 202844

October 1958

SUBJECT: FABRICATION OF INFRARED TRANSMITTING MATERIALS
BY HOT PRESSING TECHNIQUES

WADC TR 53-373 Sup 6

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INVESTIGATOR: Norbert J. Kreidl
Harold C. Hafner
Joseph R. Hensler
Eugene C. Letter
CONTRACT: AF 33(616)-5123
CONTRACTOR: Bausch & Lomb Optical Co.
ABSTRACT: The fabrication of infrared transmitting materials by hot pressing techniques has been studied. BaF_2 was used as a model material. The temperatures studied ranged from 600 to 1225°C and the pressures from 1500 to 8000 psi. The equipment used to obtain these conditions is described. The effects of various hot pressing atmospheres including nitrogen, helium, argon and carbon dioxide, were investigated. A study was carried out to identify the impurities present and to study their effects.

WADC TR 58-452
ASTIA Document No. AD 207079
OTS Release

December 1958

SUBJECT: METAL FIBER REINFORCED CERAMICS
INVESTIGATOR: R. S. Truesdale
J. J. Swica
J. R. Tinklepaugh
CONTRACT: AF 33(616)-5298
CONTRACTOR: State University of New York,
College of Ceramics at Alfred University
ABSTRACT: Techniques were developed for the sintering and hot pressing of alumina and alumina containing 5 wt. %, 10 wt. % and 20wt. % molybdenum fibers. The physical and mechanical properties of alumina containing these percentages of 1/8 in. long by 0.002 in. dia. fibers were determined and compared to those of the alumina. The alumina was superior in strength and impact resistance but there was some indication that the aluminas containing 10 and 20 wt. % additions of fiber were superior in thermal shock resistance. All alumina samples containing 10 and 20% additions developed microcracks while only some 5% samples developed these cracks.

COATINGS

WADC TR 58-199

January 1959

WADC TR 53-373 Sup 6

SUBJECT: THE USE OF BASIC MAGNESIUM CHROMATE PIGMENT IN
CORROSION INHIBITING PRIMERS

INVESTIGATOR: A. Stanley Dalton

ABSTRACT: The objective of this work was to investigate the feasibility of using basic magnesium chromate as an inhibitive pigment in metal primers which would withstand temperatures of at least 550°F. A literature survey was conducted to ascertain the amount of work previously done with this pigment. As a result of the references found and the work performed as related herein, it is concluded that basic magnesium chromate does inhibit corrosion though not as efficiently as zinc chromate at normal temperatures. It is, however, more thermally stable in the temperature range 400° - 550°F.

WADC TR 58-203

July 1958

ASTIA Document No. AD 155717

SUBJECT: PROTECTIVE COATINGS FOR TANTALUM

INVESTIGATOR: C. Arne Arenberg

CONTRACT: AF 33(616)-3983

CONTRACTOR: Armour Research Foundation

ABSTRACT: The results presented in this report cover the work period 1 March 1957 to 28 February 1958.

The program was established to determine the feasibility of protective ceramic coatings for tantalum under high temperature and high air velocity conditions. The method of coating that proved to be most practical was the "Flame Ceramics" process.

Since no single laboratory test could, at the time, be devised to duplicate the actual conditions three separate test facilities were used: (1) an oxy-acetylene cutting torch, (2) a water stabilized arc plasma, and (3) a liquid fuel rocket exhaust.

None of the tests were completely valid since the shape factor of the test specimen, the time-temperature profile, and gas velocities were not realistic. The tests established by the Chicago Midway Laboratories using the proper geometry and feeding the specimen into the plasma at a predetermined rate constitutes a more realistic approach and should be applied to any future testing programs.

However, the testing program as carried out does establish the feasibility of protective ceramic coatings for tantalum, and points up the importance of a heat sink, particularly at ultra-high temperatures. It particularly points to the need for additional research in this area.

WADC TR 53-373 Sup 6

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October 1958

SUBJECT: HIGH TEMPERATURE COATINGS FOR CHROMIUM HOT WORK
TOOL STEELS

INVESTIGATOR: Elwood B. Norris

CONTRACT: AF 33(616)-3916

CONTRACTOR: Metcut Research Associates Inc.

ABSTRACT: Chromium hot work tool steels are normally useful to approximately 1000°F provided that they are protected from corrosive atmospheres. A typical 5% chromium tool steel, Thermold J, was used to study the protective qualities of various plated, dipped or sprayed coatings. In addition to investigating the oxidation and corrosion protection, selected coatings were checked for their effect on tensile, stress-rupture and fatigue properties of the base metal at room and elevated temperature. The relative resistance of the selected coatings to abrasion and thermal shock was also studied.

From a corrosion standpoint, the best of the coatings investigated were Nickel-zinc, Aluminizing, Alumicoat and Nickel. Of the selected coatings, Aluminizing and Alumicoat reduced the strength of the base metal because of the high temperatures encountered during coating. Aluminum-silicone paint was the only coating which did not significantly reduce the fatigue strength. Watts nickel had high thermal shock resistance. Electroless nickel had the best abrasion resistance.

WADC TN 58-302
ASTIA Document No. AD 214386
OTS Release

May 1959

SUBJECT: TRANSPARENT CONDUCTING COATINGS OF GOLD ON GLASS

INVESTIGATOR: Richard E. Pawel, 1/Lt., USAF

ABSTRACT: This work on transparent conductive coatings for glass was undertaken in order to determine if there were need for further consideration of metallic films for this purpose. Gold was deposited by vacuum evaporation onto glass slides using several subcoat materials in an effort to enhance the desired properties: good mechanical adhesion, high optical transmittance, and low electrical resistance. SiO, CuO, CaO, Sb₂O₃, PbO, CeO, Cr₂O₃, SnO₂, Cu-CuO, and MgF₂ were used as substrate materials, both the substrate and the gold being deposited without breaking vacuum. Of the oxides mentioned, CuO, and SnO₂ substrates materially increased the abrasive resistance of the films, however, still not to the desired level of adherence. Thin films of gold could be produced on these substrates in the range of 50 to 70 + per cent transmittance having resistances from about 10 to 150 ohms per square. In order to increase the transmittance values about 75 per

cent, extremely high resistance values were encountered. This abnormally sharp change in the resistance characteristics is thought due to physical discontinuities in the film. Similarly, thin films of initially high transparency and resistance would not stabilize at elevated temperatures. Increasing values of transmittance were measured during heat treatment; however, for films of high transparency the effect was small.

In the range of application requiring greater than 75 per cent transmittance, the electrical stability of the subcoated gold films is poor compared with the properties of doped-oxide films. However, the thicker gold films appear more stable and may be applicable as conductors when very high transmittance is not desired.

WADC TR 58-493
ASTIA Document No. 209913
OTS Release

February 1959

SUBJECT: DEVELOPMENT AND EVALUATION OF ROCKET BLAST AND
RAIN EROSION RESISTANT COMPOSITE COATINGS PRODUCED
BY FLAME SPRAY TECHNIQUES

INVESTIGATOR: J. R. Galli B. H. Clappitt
G. I. Wheeler D. E. German
R. B. Johnson

CONTRACT: AF 33(616)-5284

CONTRACTOR: Boeing Airplane Company

ABSTRACT: It was the purpose of this contract to determine the feasibility of utilizing multilayer coatings to protect metal surfaces from erosive and corrosive effects of rocket blast impingement. These coatings were to be comprised of two or more from the group: metal, ceramic, organic primer, and organic impregnant, with the metal and ceramic layers being applied by flame spray techniques. In the course of this study six ceramics, four powder spray metals, two wire spray metals, four substrate metals, and approximately sixty organic materials were combined into a large number of different coating systems. These coatings were subjected to a wide variety of tests culminating with actual exposure to rocket blast. A total of twenty-six different coating systems were obtained which successfully withstood four rocket blasts without significant deterioration, verifying the feasibility of this technique. The successful coatings were all of the spray material-impregnant type with the most resistant spray materials being the ceramics.

In addition to the work described above, a limited amount of study was directed toward a better understanding of the flame spray process utilizing the techniques of microphotography, high speed photography, and X-ray diffraction, along with certain theoretical derivations. It is felt that the results of this work, although not of extreme usefulness by

themselves, represent a useful addition to the total knowledge about this complicated process.

WADC TR 58-545
ASTIA Document No. AD 209914
OTS Release

February 1959

SUBJECT: RESEARCH FOR COATINGS FOR PROTECTION OF NIOBIUM
AGAINST OXIDATION AT ELEVATED TEMPERATURES

INVESTIGATOR: Emanuel C. Hirakis

CONTRACT: AF 33(616)-5356

CONTRACTOR: Horizons Incorporated

ABSTRACT: Niobium metal and its alloys should have a large number of applications at temperatures above 2000°F wherever superior strength and creep resistance are required. In order for such applications to be realized, a method must be found for protecting the metal from the corrosive and embrittling influences of oxygen bearing atmospheres. This work was originally directed toward the development of a niobium base alloy which would ultimately stand exposure up to 2500°F without undue chemical or erosive attack or loss in its physical or mechanical properties. Testing programs were to be carried out at 2000, 2300 and 2500°F with up to 100 hour exposures. Such alloys were to possess ductility and stand a reasonable amount of thermal cycling. Midway in the program, the testing temperature was restricted to 2500°F and the time, ductility, bonding and thermal cycle behavior requirements were relaxed in order to obtain more useful data from the program. The use of high temperature coating materials and methods was emphasized over alloy development. Coatings were applied primarily by flame spraying and by electroplating procedures. Preparation, testing procedures and results are described for both the alloy development and coating work. In the alloy work the oxidation rate of niobium at 2000°F was reduced by about a factor of 20 by additions of cerium, chromium, titanium, and aluminum. Flame spraying and electrodeposited coatings were developed affording protection to niobium for 4-6 hours at 2500°F.

CORROSION

WADC TR 57-379
ASTIA Document No. AD 155762
OTS Release

August 1957

WADC TR 53-373 Sup 6

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SUBJECT: ROCKET EXHAUST CORROSION SIMULATOR
INVESTIGATOR: Frank B. Cramer
CONTRACT: AF 33(616)-3165
CONTRACTOR: Rocketdyne, A Division of North American Aviation, Inc.
ABSTRACT: Techniques for studying the corrosive effects of rocket exhaust gases upon various material surfaces have been developed. The designs of the recommended items of test equipment and the methods for executing these procedures are presented.

This study was initiated with an analysis of the problem areas: namely, sampling of the hot, high velocity rocket exhaust gases, uniform "simultaneous" exposure of a statistically adequate number of specimens, adequate development of corrosion, evaluation of the corrosion damage on the specimens and statistical evaluation of the utility of the techniques and equipment.

Designs were developed and checked out for a device capable of providing uniform exposure of large numbers of specimens to a single firing of a solid propellant charge. One design is presented for a laboratory device to burn small quantities (one pound) of propellants under very low hazard conditions. Another design was presented for a device capable of uniformly exposing 72 specimens to multiple samples of the hot, high velocity exhaust gases of an aircraft armament rocket.

An evaluation of the extent of corrosion damage to specimens examined by the techniques described in this report showed: that exposure was uniform from specimen to specimen, that differences could be demonstrated between different propellants and between different surfaces, that armament rockets could be compared statistically with propellant burned in a laboratory burner, and that specimens exposed to rocket exhausts during air-flight could be qualitatively compared to the specimens exposed to propellants burned in the laboratory style test fixture.

WADC TR 57-743
ASTIA Document No. AD 206895

December 1958

SUBJECT: DETERIORATION OF MATERIALS ON OPERATIONAL AIRCRAFT
INVESTIGATOR: Harold L. Stevens
ABSTRACT: Deterioration of materials on operational aircraft was studied at twenty-eight Air Force bases at various locations. Findings include data on metal corrosion, packaging, protective coatings and fungus attack with emphasis on aircraft and engine corrosion. Relation of deterioration to geographical location is discussed. Recommendations for deterioration control are included.

November 1958

SUBJECT: CORROSION OF ALUMINUM AND MAGNESIUM ALLOYS IN ALCOHOL-WATER SOLUTIONS, EVALUATED USING THE RANDOM ASSIGNMENT STATISTICAL TECHNIQUE

INVESTIGATOR: Harold L. Stevens

ABSTRACT: The effects of methanol-water and ethanol-water on magnesium and aluminum were investigated. There was no significant difference between the effects of solutions of the two alcohols. The magnesium alloys tested were more resistant to alcohol-water attack than were the aluminum alloy tested. Pure methanol catastrophically destroyed the magnesium alloys. Coupling aluminum to magnesium accelerated the attack on both metals in the presence of alcohol-water solutions. Increased exposure time did not change the corrosion rates in any solution.

The Random Assignment Statistical Technique used in this study reduced the required number of test samples from 1,152 to 84. The technique is limited to homogenous populations of approximately fifty or more samples.

CREEP

WADC TR 57-150 Pt III
ASTIA Document No. AD 155578
OTS Release

May 1958

SUBJECT: EFFECT OF PRIOR CREEP ON MECHANICAL PROPERTIES OF AIRCRAFT STRUCTURAL METALS - Part III: - C110M Titanium Alloy

INVESTIGATOR: Jeremy V. Gluck
Howard R. Voorhees
James W. Freeman

CONTRACT: AF 33(616)-3368

CONTRACTOR: The University of Michigan

ABSTRACT: A study was carried out of the effect of exposure to elevated temperature creep conditions on the subsequent mechanical properties of C110M, an 8 percent manganese binary titanium alloy. Exposures were conducted for times of 10, 50, or 100 hours either unstressed or at stresses causing up to 3 percent total deformation at temperatures between 650° and 800°F. Specimens were taken parallel to the sheet rolling direction.

Following the exposures, short-time tensile, compression or tension-impact tests were run at either room temperature or the temperature of exposure. Prior creep-exposure was found to have little effect on the fracture strength or ductility in either tensile tests or tension-impact tests. The original material had an abnormally high tension yield strength and a low compression yield strength. Exposure to temperature alone caused a decrease in the tensile yield strength and an increase in the compression yield strength depending on the exposure time and temperature, and on the test temperature. Plastic deformation either during loading, or principally during creep, resulted in an increase in the tensile yield strength and a decrease in compression yield strength from the values established by exposure to temperature alone. This behavior can be attributed to a Bauschinger-type effect.

WADC TR 58-63
ASTIA Document No. AD 155565
OTS Release

May 1958

SUBJECT: THE ROLE OF SUBGRAINS IN HIGH TEMPERATURE CREEP
INVESTIGATOR: Lawrence A. Shepard
John E. Dorn
CONTRACT: AF 33(616)-3860
CONTRACTOR: University of California
ABSTRACT: The role of the subgrain structure in the high temperature creep process is evaluated in the light of recent experimental and theoretical developments in creep theory. The origin of subgrains is discussed, as well as the specific deformation modes which produce the variety of observable substructures. The effect of creep variables on the subgrain development, size and structure is described. Finally, an attempt is made to analyse the manner in which the subgrain structure affects creep rate, recovery and grain boundary shearing. It is concluded that the contribution of the substructure to high temperature creep resistance is small relative to other factors.

WADC TR 58-204
ASTIA Document No. AD 155711
OTS Release

July 1958

SUBJECT: AN INVESTIGATION OF THE RELATIONSHIP BETWEEN
MICROSTRUCTURE AND CREEP-~~RUPTURE~~ PROPERTIES OF
HEAT-RESISTANT ALLOYS
INVESTIGATOR: A. Phillip Coldren
James W. Freeman
CONTRACT: AF 33(616)-3239
CONTRACTOR: The University of Michigan

ABSTRACT: Progress is reported for an investigation of the influence of conditions of hot working on the properties of alloys at high temperatures. Conditions of working can be used to control microstructural variations in a manner which cannot be obtained in any other procedure and is capable of developing structures superior in properties to any other treatment. The major objective is to define the basic principles involved so that they can be applied to the general problem of developing optimum properties in any alloy. The relatively simple structure of "A" Nickel is being used as an experimental material for study of the role of working for properties in the as-worked condition. A-286 alloy is being used as an example of a material whose properties are influenced after solution and aging treatments by the conditions of prior working.

The results reported cover the initial surveys of the relationships of working conditions to creep and rupture properties. Structural analyses to define the basic principles involved were confined to preliminary partial studies. The investigation is being continued with emphasis on the structural studies.

WADC TR 58-340
ASTIA Document No. 202502
OTS Release

October 1958

SUBJECT: FATIGUE, CREEP, AND RUPTURE PROPERTIES OF THE
ALLOYS UDIMET 500, HASTELLOY R-235, AND GMR-235
INVESTIGATOR: F. H. Vitovec
CONTRACT: AF33(616)-2803
CONTRACTOR: University of Minnesota
ABSTRACT: Fatigue, rupture, and creep data at 1200 and 1650°F obtained under various combinations of mean and alternating stress are presented. Tests were performed under axial stress on unnotched specimens and specimens having a theoretical stress concentration factor of 3.4. The data are presented as S-N curves and stress range diagrams to show the effect on the fatigue and creep properties of stress concentration, temperature, ratio of alternating-to-mean stress, and stress magnitude.

DESIGN CRITERIA

WADC TR 52-251 Pt 5
ASTIA Document No. AD 155604

June 1958

WADC TR 53-373 Sup 6

OTS Release

SUBJECT: THE COMPRESSIVE CREEP BUCKLING OF METAL COLUMNS
Part 5 - Cyclic Loading

INVESTIGATOR: A. Rudnick
R. L. Carlson
G. K. Manning

CONTRACT: AF 33(616)-3317

CONTRACTOR: Battelle Memorial Institute

ABSTRACT: Tests were conducted to determine the effect of load cycling on the creep buckling behavior of metal columns. Two materials were investigated: 2024-T4 aluminum alloy columns with length to radius of gyration ratios of 81.2 and 55.7 were tested at 350°F and 450°F; C-110M titanium alloy columns having a length to radius of gyration ratio of 90 were tested at 700°F and 800°F. The cycling period used was 24 hours, the time the load was on in that period was the variable. In addition to the cyclic load tests, constant load tests were conducted to obtain background information.

A linear relationship was found between the time to creep buckling under constant load and the reciprocal of the minimum creep deflection rate. This relationship was used in interpreting the cyclic load test results.

The effect of load cycling proved to be dependent upon the properties of the material at the testing temperature. Two criteria, based upon material stability characteristics, are set up to help classify the cyclic load data.

WADC TR 52-251 Pt VI
ASTIA Document No. AD 202491
OTS Release

October 1958

SUBJECT: THE COMPRESSIVE CREEP BUCKLING OF METAL COLUMNS
Part VI. Effect of Initial Imperfection

INVESTIGATOR: Alfred Rudnick
Robert L. Carlson
George K. Manning

CONTRACT: AF 33(616)-3317

CONTRACTOR: Battelle Memorial Institute

ABSTRACT: Tests were conducted to determine the effect of the initial imperfection of a column on its creep-buckling characteristics. The material used was 6Al-4V titanium alloy. Columns with initial imperfections ranging from $\frac{L}{1000}$ to $\frac{L}{70}$ (where L is the column length) were tested at temperature of 750, 850 and 900°F.

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Initial imperfection was found to influence very strongly the creep-buckling behavior of a column. In general, a significant inter-relationship was found to exist between column load, lifetime, temperature, and imperfection, i.e., the effects of any one factor are dependent upon the magnitudes of the other factors.

The time-dependent secant- and tangent-modulus methods for estimating column capacity were investigated. It is shown that both estimates can be either conservative or nonconservative, depending upon the temperature and initial imperfection of the column.

The Larson-Miller time-temperature parameter technique was applied to the data. The usefulness of this and similar parameters for correlating column-creep data is discussed.

WADC TR 58-246
ASTIA Document No. AD 155863
OTS Release

August 1958

SUBJECT: DETERMINATION OF MATERIALS DESIGN CRITERIA FOR
6Al-4V TITANIUM ALLOY AT ROOM AND ELEVATED TEMPERATURES
INVESTIGATOR: J. K. Childs
M. M. Lemcoe
CONTRACT: AF 33(616)-3348
CONTRACTOR: Southwest Research Institute
ABSTRACT: In order to establish design criteria on the 6Al-4V titanium alloy, tensile, compressive, bearing and shear properties have been determined on both bar and sheet material at temperatures from 75 to 1000°F. In addition, tensile properties of sheet material were determined after 100-hour exposure at 600, 800 and 1000°F.

Test results were compared with recently established minimum requirements for tensile strength in order to derive design values for compression, bearing, and shear.

Other properties investigated include minimum bend radius for 105° bend and notched tensile strength at temperatures from 75 to 1000°F, and torsional properties at room temperature.

Axial load fatigue characteristics were investigated at temperatures from 75 to 1000°F for both smooth and notched specimens at stress ratios of 0 (stress-rupture), 0.3, 1.0, and infinity.

Descriptions of the test specimens, equipment, and procedures used are included. Test results are reported in tables and in curves showing the effect of temperature on the various mechanical properties. The

derived design data and curves are presented in a form suitable for inclusion in ANC-5.

WADC TR 58-365
ASTIA Document No. AD 206075
OTS Release

November 1958

SUBJECT: DETERMINATION OF TENSILE, COMPRESSIVE, BEARING AND
SHEAR PROPERTIES OF SHEET STEELS AT ELEVATED TEMPERATURES
INVESTIGATOR: J. Robert Kattus
James B. Preston
Herman L. Lessley
CONTRACT: AF 33 (616)-3876
CONTRACTOR: Southern Research Institute
ABSTRACT: The tensile, compressive, bearing, and shear properties
of the following sheet metals were determined at various temperatures after
exposure times of from 1/2 hour to 1000 hours at the test temperature:

1. A-286 austenitic alloy, quenched and tempered
2. 17-7 PH stainless steel, RH950 condition
3. Thermold J. alloy steel, quenched and tempered
4. Type 420 stainless steel, quenched and tempered
5. Type 422 stainless steel, quenched and tempered
6. 17-22 A (S) alloy steel, quenched and tempered

The A-286 alloy was tested over a temperature range from 75°F to 1200°F, the Thermold J from 75°F to 1100°F, and the other alloys from 75°F to 1000°F.

In all of the test alloys, the strength properties and moduli of elasticity decreased with increasing temperatures. The strength properties of the Thermold J, Type 420, Type 422, and 17-22 A (S) tended to decrease by varying amounts with increasing exposure times at the higher test temperatures. These decreases in strength are believed to be associated with structural changes produced by tempering. At lower temperatures, the properties of these materials did not vary significantly with exposure time, indicating that the structures were stable at those temperatures. The strength properties of the A-286 alloy and the 17-7 PH (RH 950) stainless varied somewhat erratically with increasing exposure times at the higher test temperatures as a result, probably, of aging phenomena in both of these precipitation-hardening alloys.

The simple ratio relationships between various properties under equivalent test conditions were approximately equal in magnitude and in consistency to those previously determined for other materials and reported in WADC Technical Report 56-340. For the entire ranges of materials and conditions used in this work, the consistency of the various property relationships ranged from $\pm 17\%$ to $\pm 71\%$. Precise data on the mechanical properties

of aircraft-structural materials can be obtained only by testing under the desired condition.

WADC TR 58-400
ASTIA Document No. AD 208322
OTS Release

January 1959

SUBJECT: MECHANICAL PROPERTIES OF 17-7 PH AND PH 15-7 MO.
STAINLESS STEEL
INVESTIGATOR: Alton W. Brisbane
ABSTRACT: Two stainless steels were investigated in this work, 17-7 PH (RH-950 Condition) and PH 15-7 Mo. (RH-950 and TH-1050 Conditions).

Tensile stress-strain test results for the 17-7 PH and the PH 15-7 Mo. stainless steel are presented for temperatures from room temperature to 1000°F. Compression and bearing data were also obtained at room temperature.

A comparison is made between these two stainless steels and other materials.

WADC TR 58-440 Pt I
ASTIA Document No. AD 206074
OTS Release

November 1958

SUBJECT: TENSILE PROPERTIES OF AIRCRAFT-STRUCTURAL METALS AT
VARIOUS RATES OF LOADING AFTER RAPID HEATING
INVESTIGATOR: Haywood E. Dedman
Edmund J. Wheelahan
J. Robert Kattus
CONTRACT: AF 33(616)-3996
CONTRACTOR: Southern Research Institute
ABSTRACT: The purpose of this work was to evaluate the short-time tensile properties of aircraft-structural materials under conditions of rapid heating, short times at temperature, and moderate to rapid rates of loading. The test specimens were heated to the test temperatures within ten sec, held for periods of time ranging from 10 sec to 1800 sec, and loaded at strain rates from 0.00005 to 1.0 in./in./sec. Major emphasis was placed on the accurate determination of 0.2% offset yield strength and ultimate tensile strength. The modulus of elasticity, percent elongation, proportional limit, and full stress-strain curves were determined with somewhat less accuracy but, nevertheless, with sufficient accuracy to establish trends.

Four steels--Chro-Mov tool steel, Thermold-J tool steel, Peerless-56 tool steel, and AM-350 precipitation-hardening stainless steel--

and 6Al-4V titanium alloy were fully evaluated, the steels being tested at temperatures up to 1200°F and the titanium alloy up to 1000°F. Before being tested, all of these alloys were heat treated to high strength levels of about 300,000 psi for the tool steels, 200,000 psi for the AM-350, and 160,000 psi for the 6Al-4V.

Similar evaluations, except for the determination of complete stress-strain curves, had previously been carried out on seventeen alloys under contract AF 33(616)-424 and reported in WADC Technical Report 55-199 Parts I, II, and III. For these alloys, complete stress-strain curves were obtained in the present contract under all test conditions employed in the previous contract.

The test results show that, at the lower test temperatures, the strength properties of the test alloys tended to increase slightly or to remain constant with increasing strain rates. Near the maximum test temperatures, the effect of strain rate became much greater, the strength properties increasing greatly with increasing strain rates.

Probably as a result of structural changes associated with tempering and with overaging the strength of the steel alloys decreased with increasing holding times at 1200°F. The tensile properties of the steel alloys at lower temperature and of the titanium alloy at all test temperatures were not affected by variations in holding time.

WADC TR 58-440 Pt II
ASTIA Document No. AD 213834
OTS Release

May 1959

SUBJECT: TENSILE PROPERTIES OF AIRCRAFT-STRUCTURAL METALS
AT VARIOUS RATES OF LOADING AFTER RAPID HEATING
INVESTIGATOR: J. Robert Kattus
CONTRACT: AF 33(616)-3996
CONTRACTOR: Southern Research Institute
ABSTRACT: In this report, a summary and an analysis are presented of the results of five years of investigation of the short-time tensile properties of structural metals. The specimens that were tested in this investigation were heated to various elevated test temperatures within 10 sec, were held at test temperature for periods of time from 10 sec to 30 minutes, and were then loaded to failure at strain rates from 0.00005 to 1.0 in./in./sec.

The strength properties of all of the test metals tended to decrease with increasing temperatures. Variations in holding time at test temperature had no significant effect upon the tensile properties of the structurally stable metals. The tensile properties of the unstable alloys changed with variations in holding time at certain temperatures as a result

of time-temperature-dependent structural changes. In general, increasing strain rate produced increased strength in the test metals, the percentage increases in strength being relatively small in the temperature ranges of low-temperature behavior and quite large in the temperature ranges of high-temperature behavior. Under certain conditions, the effects of time-temperature-dependent and strain rate-temperature-dependent structural changes were superimposed upon, and sometimes obscured, the inherent effects of temperature and of strain rate.

An evaluation of time-temperature and rate-temperature parameters indicated that short-time tensile properties cannot be expressed with a high degree of accuracy as invariant functions of such parameters. Nevertheless, illustrations of short-time tensile properties as functions of the Larson-Miller parameter are quite useful for general comparisons of the strength levels of various materials over wide ranges of conditions. A duplex method that was developed for the presentation of tensile-strength data is useful primarily for the accurate condensation of tensile data over wide ranges of conditions into simple one-page plots. Such presentations, however, are not particularly useful for comparisons among different materials or for extrapolations of tensile data beyond the experimental conditions.

WADC TR 58-672
ASTIA Document No. AD 208664
OTS Release

February 1959

SUBJECT: MECHANICAL PROPERTIES OF AM350 and AM355 STAINLESS STEELS

INVESTIGATOR: Alton W. Brisbane

ABSTRACT: In this report are presented the results of smooth and notched tension tests and compression, bearing, bending and Charpy V-notched impact tests. The tests were conducted on two heats of Allegheny-Ludlum AM-350 stainless steel sheet which is a Cr.-Ni.-Mo. stainless steel hardenable by subzero cooling or double aging, and one heat of AM-355 3/4 inch diameter bar material. This material was tested at room and elevated temperatures in tension plus some subnormal and elevated temperature Charpy impact tests.

The material was given several heat treatments to determine the effect on mechanical properties. Varying the aging temperatures had some effect on the strength properties and ductility.

The sub-zero treatment with no elevated temperature aging gives the maximum strength but not the best ductility.

The -100°F + 950°F heat treatment gives the best ductility

for this material, as shown in the elongation, reduction in area and energy absorbed in the impact test.

ELECTRODEPOSITION

WADC TR 58-481
ASTIA Document No. AD 206386

December 1958

SUBJECT: A NEW LOOK AT THE HYDROGEN EMBRITTLEMENT OF
CADMIUM COATED HIGH STRENGTH STEELS

INVESTIGATOR: Norman M. Geyer
G. William Lawless
Bennie Cohen

ABSTRACT: A reliable and sensitive test procedure for ascertaining detrimental hydrogen embrittlement as a result of cadmium plating has been established. The test consists of a sustained loaded notched tensile specimen, loaded at 75% of the ultimate notched tensile strength for a minimum of 200 hours.

Detrimental hydrogen embrittlement is shown to be dependent upon the steel alloy, the current efficiency of the cadmium plating bath, and the physical structure of cadmium coating obtained. Current efficiency-current density curves have been obtained for the conventional cadmium cyanide bath, the high efficiency cadmium cyanide bath, the cadmium sulfamate bath, and the cadmium fluoborate bath.

Cadmium electroplating processes for coating high strength steel, 280,000 psi UTS, without detrimental hydrogen embrittlement are given. Vacuum cadmium metallized coatings are also shown to be non-embrittling to high strength steels.

ENVIRONMENT

WADC TR 56-600
ASTIA Document No. AD 208141

January 1959

SUBJECT: SOLAR RADIATION AND WEATHER DATA SOUTH CENTRAL
NEW MEXICO
INVESTIGATOR: A. M. Lukens
A. E. Prince
CONTRACT: AF 33(616)-3275
CONTRACTOR: New Mexico College of Agriculture and Mechanic Arts
ABSTRACT: The daily recordings of maximum and minimum temperatures, relative humidities, and the intensity of solar radiation on a surface slanted 45° facing to the south are tabulated with the monthly averages and totals of each factor. These data have been collected, compiled, and recorded in connection with work concerning the effects of actinic and biological agents of deterioration on Air Force materials. Charts are included showing a summary of temperature and humidity data from August 1947 through September 1956 and solar radiation data from June 1951 through October 1956.

WADC TR 57-173
ASTIA Document No. AD 151190

May 1958

SUBJECT: METEOROLOGICAL AND SOLAR RADIATION DATA COLLEGE, ALASKA
INVESTIGATOR: Wm. S. Wilson
CONTRACT: AF 18(600)-40
CONTRACTOR: University of Alaska
ABSTRACT: The daily observations of maximum and minimum temperatures, maximum, minimum, and mean of the relative humidity with the approximate time (Alaskan Standard Time) of the occurrence of each maximum and minimum, maximum intensity of solar radiation and total radiation received on a horizontal surface and a surface slanted 45° to the south are tabulated along with the monthly averages and totals of each of these factors as obtained in connection with the project on the "Exposure of USAF Materials near College, Alaska." The temperature data in each year are represented on a composite graph. The monthly values of all data are tabulated in separate tables. The period covered is from 1 September 1955 through 9 March 1957.

FATIGUE

WADC TR 56-127 Pt II
ASTIA Document No. AD 214385
OTS Release

May 1959

SUBJECT: EFFECT OF CHANGING CYCLIC MODULUS ON BENDING
FATIGUE STRENGTH

WADC TR 53-373 Sup 6

INVESTIGATOR: A. A. Blatherwick
B. J. Lazan
CONTRACT: AF 33(616)-5449
CONTRACTOR: University of Minnesota
ABSTRACT: The influence of the observed increasing cyclic modulus in super-purity aluminum on stress distribution in bending-fatigue specimens is discussed. The resulting stress redistribution is examined for the various types of fatigue tests in common use. Differences in published fatigue data are partially explained in the light of this stress redistribution. It is concluded that for a cyclic strain hardening material, such as high purity aluminum, constant strain (or deflection) tests are more severe than constant moment tests, and the latter in turn are more severe than constant stress tests. Some observations of the development of slip bands and fatigue cracks are presented.

WADC TR 58-36
ASTIA Document No. AD 155705
OTS Release

July 1958

SUBJECT: ENERGY DISSIPATION IN LONGITUDINAL VIBRATION
INVESTIGATOR: C. S. Chang
L. E. Goodman
CONTRACT: AF 33(616)-2803
CONTRACTOR: University of Minnesota
ABSTRACT: The problem of the longitudinal vibrations in a finite prismatic bar with a terminal viscous damper is solved. The complete boundary value problem (forced vibration with arbitrary initial conditions) is first split into two parts according to the method developed by Mindlin and Goodman. One of these parts yields the steady-state solution and the other represents a free-vibration problem, which is then solved by the method of Boussinesq.

Examples of the applications of the general solutions are given and the amount of mechanical energy dissipated through the damper is computed.

WADC TR 58-43
ASTIA Document No. AD 155772
OTS Release

August 1958

SUBJECT: RESEARCH ON FERROUS MATERIALS FATIGUE
INVESTIGATOR: Harold N. Cummings
Foster B. Stulen
William C. Schulte

WADC TR 53-373 Sup 6

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CONTRACT: AF 33(616)-5182
CONTRACTOR: Curtiss-Wright Corporation
ABSTRACT: Three studies of the effect of fatigue stressing on steel R. R. Moore rotating beam specimens were made, - (1) the rate of propagation of fatigue cracks, (2) the effect, on fatigue strength, of surface hardening by shot peening and plating, by carburizing, and by nitriding, and (3) the transverse properties of SAE 4340 steel. An equation is proposed expressing fatigue crack length as a function of fatigue life. The increased strength produced by surface hardening is indicated and certain limitations on the use of Prot method testing are incidentally brought to light and discussed. Some decrease in transverse strength as compared with longitudinal strength is revealed and discussed for rolled and forged SAE 4340 steel.

WADC TR 58-69 Pt I
ASTIA Document No. AD 155687
OTS Release

June 1958

SUBJECT: ON STRESS INTERACTION IN FATIGUE AND A CUMULATIVE DAMAGE RULE - Part I - 2024 Aluminum and SAE 4340 Steel Alloys
INVESTIGATOR: Alfred M. Freudenthal
Robert A. Heller
CONTRACT: AF 33(616)-3982
CONTRACTOR: Columbia University
ABSTRACT: The object of this investigation was to determine the effects of stress-interaction, under randomly varied exponentially distributed stress amplitudes representing gust and maneuver loads on aircraft wings, on the fatigue life of smooth 2024 aluminum and SAE 4340 steel alloy specimens. On this basis a quasi-linear cumulative damage theory supported by numerous test results is developed. The lack of significance of the conventional endurance limit under random loading is demonstrated.

The tests were performed on specially built rotating bending random load fatigue machines.

WADC TR 58-72
ASTIA Document No. AD 155747
OTS Release

July 1958

SUBJECT: VARIOUS ASPECTS OF THE DISTRIBUTION OF FATIGUE LIVES
INVESTIGATOR: E. J. Gumbel
CONTRACT: AF 33(616)-3982
CONTRACTOR: Columbia University

WADC TR 53-373 Sup 6

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ABSTRACT: The report deals with the following aspects of the asymptotic probability function of limited smallest values that is being used for the representation and interpretation of both constant stress-amplitude and random fatigue tests and for the estimate of the minimum fatigue life:

(a) Transformation of the probability functions for large values of the scale parameter;

(b) Probability function for the relative life defined as the fatigue life divided by the characteristic value;

(c) Relation between scale-parameter and minimum life;

(d) Nomograms for the rapid estimation of the parameters of the probability function.

WADC TR 58-128
ASTIA Document No. AD 155851

August 1958

SUBJECT: HEAT TREATMENT RESPONSE, MECHANICAL
PROPERTIES AND STABILITY OF TITANIUM SHEET ALLOYS

INVESTIGATOR: E. A. Sticha
F. W. Richards

CONTRACT: AF 33(616)3586

CONTRACTOR: Crane Co.

ABSTRACT: Tensile and bend test data indicate that the three titanium sheet alloys studied in this investigation have formability, when solution treated and quenched from an intermediate temperature in the alpha-beta phase field, equal to or better than annealed materials of these same compositions. Formability is not likely to be improved by heating to moderate temperature but less power would be required for forming. Best ductility is exhibited by the alloys of low interstitial content. Compositions with the greatest total alloy content give the highest strength and lowest ductility.

It is possible to obtain high strength with satisfactory ductility by application of a solution treat, quench and age type of heat treatment to these alloys. The heat treatment for optimum properties varies with the interstitial content and, possibly, with nature of the interstitial elements. However, the interstitial elements seem to contribute to strength properties without detracting from ductility in the heat treated alloys. The solution temperature for maximum strength with satisfactory ductility is sometimes the same as that for maximum formability. Strain influences response to the subsequent aging treatment and results in properties which suggest overaging.

Short-time strength decreases with increasing temperature and, somewhat anomalously, so do ductility values. The effect of interstiti-

al elements persists at high temperatures. The materials exhibit rather good creep resistance at 800F with Ti: 6Al: 4V alloy having the highest strength and the Ti: 4 Al complex alloy the lowest. This is the same order of strength as determined by elevated temperature tensile testing. Exposure at 800F may produce some embrittlement in the Ti: 6Al: 4 V alloys and the high interstitial Ti: 4 Al complex alloy but the results are not conclusive.

WADC TR 58-214
ASTIA Document No. AD 155738
OTS Release

July 1958

SUBJECT: EFFECT OF STATIC PRESTRAIN ON THE PROT-FATIGUE
PROPERTIES OF UNNOTCHED AND NOTCHED MATERIALS
AT ROOM AND ELEVATED TEMPERATURE

INVESTIGATOR: F. H. Vitovec
CONTRACT: AF 33(616)-2803
CONTRACTOR: University of Minnesota

ABSTRACT: A study was conducted on the effect of short time and creep prestrain on the fatigue properties of unnotched and notched specimens of the alloys 7075-T6 extruded, 2024-T4 extruded, 16-25-6 hot-cold-worked, and S-816 solution treated and aged. Fatigue properties were determined using a Prot-type test with a single loading rate of 0.01 psi per cycle. The unnotched and notched specimens were prestrained at test temperature and then immediately subjected to a Prot-type fatigue test at the same temperature and in the same testing machine. The test temperature for the short time prestrain and creep prestrain respectively were 75 and 300°F for 7075-T6, 300 and 500°F for 2024-T4, 1200°F for 16-25-6, and 1500°F for S-816. Short time prestrains up to 10 percent were applied. Stresses used for the creep prestrains corresponded to those which produced rupture in 100 to 200 hours at test temperature.

The main factors influencing the Prot-failure stress were residual stresses, metallurgical reactions, and cracks produced by prestraining. Strain hardening and relaxation of residual stress appeared to be of secondary importance for the materials and range of testing variables investigated.

WADC TR 58-289
ASTIA Document No. AD 208321
OTS Release

February 1959

SUBJECT: THE EFFECT OF METALLURGICAL VARIABLES ON THE FATIGUE
PROPERTIES OF AISI 4340 STEEL HEAT TREATED IN THE
TENSILE STRENGTH RANGE 260,000-310,000 PSI

WADC TR 53-373 Sup 6

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INVESTIGATOR: James I. Fisher & J. P. Sheehan
CONTRACT: AF 33(616)-3299
CONTRACTOR: Armour Research Foundation
ABSTRACT: Eight heats of AISI 4340 were melted by several different methods in an effort to produce a variety of nonmetallic inclusions. The fatigue properties of these steels were studied at the 260,000-310,000 psi strength level by the rotating beam method using both standard and cylindrical R. R. Moore specimens. The endurance limits were determined by the Prot method and by the constant stress method. It was found, after a study of the size of the nonmetallic inclusions in each heat, that a fair correlation existed between the mean width of the largest inclusions and the ratio of endurance limit to ultimate tensile strength. The smaller the mean diameter of inclusions, the higher the endurance limit/tensile strength ratio.

Experiments were also performed in an effort to determine the effect of reducing the amount of retained austenite and dissolved hydrogen and nitrogen on the fatigue properties. No effect was observed, possibly because of the overriding influence of large inclusions in the heat tested.

WADC TR 58-430
ASTIA Document No. AD 206384
OTS Release

December 1958

SUBJECT: INVESTIGATION OF STATIC AND FATIGUE STRENGTH OF METALS SUBJECTED TO TRIAXIAL STRESSES
INVESTIGATOR: William Lehrer & Harry Schwartzbart
CONTRACT: AF 33(616)-3237
CONTRACTOR: Armour Research Foundation
ABSTRACT: The objectives of this program were: (1) the determination of the effect of triaxial stresses on fracture in static and dynamic loading and (2) determination of the brittle fracture strength of metal in the absence of any preceding plastic flow. To achieve these objectives, use was made of a composite brazed specimen consisting of a thin disk of soft metal between cylinders of hard metal. When a load is applied to the brazed bars, a triaxial stress condition is created due to the plastic restraint on the metal by the harder steel cylinder interfaces.

Although base metals of mild steel and 4340 steel, and filler metals of lead, cadmium, and silver were utilized, significant data were obtained only with the silver filler metal and 4340 base metal.

Experimental procedures and equipment were developed for producing sound and voidless brazements over a range of joint thicknesses for accurately measuring joint thickness and for determining the tensile and fatigue properties of such brazements with a minimum of scatter.

The static tensile strength of silver butt brazements in 4340 steel increases with decreasing joint thickness because of increasing triaxiality of stress, reaches a maximum at a joint thickness of -1.5×10^{-4} in., and falls to a relatively constant value of 26,000 psi at thicknesses less than 4×10^{-5} in. The maximum strength is greater than 110,000 psi, some $7 \frac{1}{2}$ times the strength of cast silver in uniaxial tension. The ultimate tensile strength of pure cast silver has been determined to be approximately 15,000 psi.

The fatigue life of silver-brazed butt joints in 4340 steel increases continuously with decreasing joint thickness for both fluctuating tension and completely reversed axial loading over the entire range of joint thicknesses investigated, 3×10^{-4} in. to 1.8×10^{-2} in. Also determined and included with these data are the fatigue properties of pure cast silver to simulate the infinitely thick joint.

Relationships between the appearance of the fracture surfaces and the mechanical properties are drawn, where possible.

WADC TR 58-461
ASTIA Document No. AD 207792
OTS Release

January 1959

SUBJECT: A SYSTEM FOR AUTOMATIC PROCESSING OF FATIGUE DATA
INVESTIGATOR: A. J. Belfour
W. S. Hyler
CONTRACT: AF 33(616)-3300 and AF 33(616)-3301
CONTRACTOR: Parsons Corporation and Battelle Memorial Institute
ABSTRACT: This report presents and discusses a system for coding of fatigue information on IBM cards for subsequent automatic processing of the data. Certain codes are needed for some types of entries; the design and preliminary development of these codes are included.

The card system devised will permit coding not only the basic fatigue information (stress and lifetime) but also pertinent information describing: (1) the basic material and fabrication, (2) mechanical properties of the materials, (3) specimen design and methods of preparation, and (4) type of test and associated testing procedure. The system is useful in coding information from basic fatigue studies of materials as well as component and structural fatigue studies.

WADC TR 58-539
ASTIA Document No. AD 206665
OTS Release

December 1958

SUBJECT: GRAIN SIZE EFFECTS ON FATIGUE AND THEIR RELATIONSHIP
TO NOTCH GEOMETRY, STRESS GRADIENT AND SIZE OF SPECIMENS
INVESTIGATOR: F. H. Vitovec
CONTRACT: AF 33(616)5449
CONTRACTOR: University of Minnesota
ABSTRACT: A study was conducted on the effect of grain size, size of specimen and stress gradient on the direct stress fatigue strength of a 2.5 Al-magnesium alloy at room temperature. Specimens with three different grain sizes and seven different notch sizes were used in this investigation. The data are analyzed with regard to relationships between grain size, size of notch, relative stress gradient, stress gradient per grain, and theoretical strength of notched specimens.

WADC TR 58-570
ASTIA Document No. AD 214383
OTS Release

May 1959

SUBJECT: THE RANDOM VIBRATION OF ELASTIC STRINGS--THEORETICAL
INVESTIGATOR: Richard H. Lyon
CONTRACT: AF 33(616)5426
CONTRACTOR: University of Minnesota
ABSTRACT: The response of a perfectly flexible string with longitudinal deformation to random excitation is studied in some detail. The equations of motion are essentially those of Carrier (Quart. App. Math., 3, 157-165). The modified mean square response for the "elastic" strings is discussed and it is shown that the mean square deflection is diminished from the linear case. From a study of the fourth moments, it also appears that the shape of probability distributions of the transverse displacement are altered, the response to gaussian noise being in general non-gaussian.

FUELS

WADC TR 53-63 Pt VI
ASTIA Document No. AD 151193

May 1958

SUBJECT: RESEARCH ON DETERMINATION OF THE STABILITY OF JET
ENGINE FUELS
INVESTIGATOR: Alan C. Nixon Harry B. Minor
Roy E. Thorpe Ted R. Lusebrink
CONTRACT: AF 33(616)-3888
CONTRACTOR: Shell Development Company

WADC TR 53-373 Sup 6

ABSTRACT: The Emeryville Research Center of Shell Development Company has continued the investigation of the effects of environment and composition on the thermal and radiation stability of jet fuels. During the past year the major effort has been devoted to the study of radiation damage as a function of dosage and fuel composition. The relation between most properties and log dosage follows an exponential curve in the range 10^7 - 10^9 r, but the thermal stability undergoes a sinusoidal type of change, the greatest degradation occurring at 10^7 r or below with an improvement over base occurring at about 10^8 r, followed again by degradation at higher dosages. An apparent major degrading effect of combined neutron-gamma flux (in SPT) now appears to be mainly due to the gamma flux level and to solution of iron. The latter (and also copper) has a marked degrading effect.

Some antioxidants and dispersants have been found to have a beneficial effect on thermal stability even after storage, but the effect of radiation has not yet been completely determined. It appears that metal deactivators (in a metal-containing fuel) cannot be relied upon to eliminate the adverse effect of the metal on thermal stability.

In view of the degrading effect of aromatics on thermal stability, a completely saturated fuel seems to be the best choice for a fuel to be used in a radiation environment, although there is some evidence that fuels containing a high proportion of C_5 rings should be avoided.

GRAPHITE

WADC TR 58-152

August 1958

ASTIA Document No. AD 155804

SUBJECT: STUDY OF THE MECHANISM OF FAILURE OF ROCKET MATERIALS

INVESTIGATOR: Yehuda Baskin
Thomas A. Greening

CONTRACT: AF 33(616)-3925

CONTRACTOR: Armour Research Foundation

ABSTRACT: Twenty-five different materials were evaluated as nozzle inserts in rocket motors utilizing typical solid propellants. Evaluation of each material consisted of its exposure to the high temperature sonic gas flow of solid propellant engines under conditions of high internal chamber pressure for relatively short periods. Some of the nozzle materials were incorporated in subsequent trials at various combinations of chamber pressure and duration. Unfired and fired nozzles were examined, utilizing x-ray dif-

fraction, microscopic, chemical, metallographic, and other analytical techniques. Chemical changes taking place in the nozzle as a consequence of firing are described. The mechanisms considered responsible for deterioration of the various materials are discussed in detail.

WADC TR 58-152 Sup 1
ASTIA Document No. AD 207779

January 1959

SUBJECT: STUDY OF THE MECHANISM OF FAILURE OF ROCKET MATERIALS
INVESTIGATOR: Yehuda Baskin
Thomas A. Greening
CONTRACT: AF 33(616)-3925
CONTRACTOR: Armour Research Foundation
ABSTRACT: Twenty-five different materials were evaluated as nozzle inserts in rocket motors utilizing typical solid propellants. Evaluation of each material consisted of its exposure to the high temperature sonic gas flow of solid propellant engines under conditions of high internal chamber pressure for relatively short periods. Some of the nozzle materials were incorporated in subsequent trials at various combinations of chamber pressure and duration. Unfired and fired nozzles were examined, utilizing x-ray diffraction, microscopic, chemical, metallographic, and other analytical techniques. Wear parameter data, shadowgraphs, and macrophotographs are presented.

WADC TR 58-395
ASTIA Document No. AD 204216

November 1958

SUBJECT: FURTHER STUDIES OF GRAPHITE-BASED MATERIALS FOR
HIGH TEMPERATURE APPLICATIONS
INVESTIGATOR: M. Janes
CONTRACT: AF 33(616)-3537
CONTRACTOR: National Carbon Company
ABSTRACT: Recent aerodynamic developments require a material which will endure under conditions of high heat flux, with consequent high surface temperatures and high velocity flow of an oxidizing gas relative to a body of the material. Surface temperature rise may be quite rapid so that the material must possess resistance to thermal shock. Graphite has outstanding high temperature strength, a high sublimation temperature, and excellent thermal shock resistance in comparison to other agglomerate bodies. However, it is quite reactive with oxygen, or other oxidizing gas, at high temperatures and high relative gas flow rates.

This report summarizes the results of a 6-month period of a continuing program to study the behavior of graphite- or carbon-based materials under conditions of exposure to high heat flux with consequent high

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surface temperatures at high relative gas-flow rates of an oxidizing gas. Materials which showed promise in earlier work previously reported have been more intensively studied and tested at higher relative air-flow rates. Carbon and graphite materials prepared with normal variations in carbon technology, such as the raw materials for filler component and binder, particle sizing, method of forming, etc., continue to show relatively minor differences in oxidation-erosion rate. Materials of promise, even under the relatively more severe conditions of air-flow rate, include graphite coated with pyrolytic carbon, graphite impregnated with AlF_3 , and graphite coated with silicon carbide or silicon nitride. Combinations of graphite with carbides, such as boron carbide and silicon carbide, with the carbide incorporated throughout the body, show substantially improved oxidation-erosion resistances at the more severe conditions of high relative air-flow rate. However, comparatively poorer behavior is to be anticipated at surface temperatures above about 1700°C.

WADC TR 58-503
ASTIA Document No. 208324
OTS Release

January 1959

SUBJECT: GRAPHITE TECHNOLOGY
INVESTIGATOR: Samuel W. Bradstreet
CONTRACT: AF 33(616)-5185
CONTRACTOR: Armour Research Foundation
ABSTRACT: The two-fold purpose of this investigation has been to correlate the properties of small, multicrystalline graphite specimens with the factors believed to influence them, and to assess the probability that graphite can conform to engineering specifications.

The technique of differential thermal analysis was found applicable to investigating binder pyrolysis. Three promising binder materials were selected for future work: coal-tar pitch, furfuryl alcohol, and phenol-benzaldehyde.

The most illuminating properties of experimental mixtures were found to be: apparent (water immersion) density, dynamic (sonic) modulus, volume electrical resistance, and flexural strength. Measurements of modulus, strength, and thermal expansion have been carried out to temperatures exceeding the creep threshold of graphite, between 2100 and 2250°C.

Solvent mixing techniques for insuring homogeneous distribution of the binder were found to improve reproducibility, in all cases some change in the rheology of the system was observed with time. Maximum density and strength in pitch-bonded coke was achieved after "aging" the mix at 125°C under partial vacuum. Maximum density consistent with good thermal shock resistance was obtained by adding Thermax to the coke flour. With 14 percent by weight of Thermax specimens were made having densities exceeding 1.8 gm/cc with room-temperature strengths of about 2500 psi.

Dynamic flexural moduli were measured for specimens heated and cooled between room temperature and 2650°C. Specimens cut from a block of commercial, impregnated, molded graphite increased 175 percent in flexural strength when heated to 2000°C. Such heating caused a significant permanent change in dimension, modulus, and volume resistance.

It is concluded that small graphite specimens can be made to conform to engineering specifications.

GREASES

WADC TR 56-608
ASTIA Document No. AD 155582

June 1958

SUBJECT: SIMULATED TROPICAL STORAGE CHARACTERISTICS OF
AIRCRAFT GREASES

INVESTIGATOR: Herbert Schwenker
Howard D. C. Hill

ABSTRACT: This study was initiated to determine the tropical storage life of representative specification greases. Samples of these materials were stored in one pound cans at a temperature of $85^{\circ} \pm 5^{\circ}\text{F}$ and at a relative humidity of $95\% \pm 5\%$ for periods of time up to three years. These conditions were selected as representing the average storage conditions occurring at tropical USAF depots or tactical field storage from year to year. Samples of each of the greases stored were evaluated prior to storage and at regular twelve month intervals thereafter.

Tests indicate that, of the four representative specification greases evaluated (Specifications MIL-G-3278, MIL-L-3545, MIL-L-6032, and MIL-L-7711), only the MIL-L-3545 and MIL-L-7711 greases maintained specification requirements throughout the three year tropical storage period. However, the standard specification grease containers were inadequate for direct exposure to tropic conditions.

WADC TR 58-288 Pt I
ASTIA Document No. AD 155855

August 1958

SUBJECT: DEVELOPMENT OF HIGH TEMPERATURE, HEAVY LOAD-CARRYING
GREASES

WADC TR 53-373 Sup 6

INVESTIGATOR: Robert K. Smith
William Eismann, Jr.
CONTRACT: AF 33(616)-5156
CONTRACTOR: E. F. Houghton & Company
ABSTRACT: The object of this study has been to develop greases which are capable of lubricating heavily loaded (50,000 to 75,000 psi.) - rod ends, pulleys, anti-friction bearings, sliding surfaces of hinge components, gear boxes, and plain bearings subjected to oscillatory motion. The temperature range over which these greases are to operate is from -65°F to 425°F. Greases were prepared from both conventional and recently developed silicone and ester oil base fluids thickened by Bentone 38 or aryl substituted urea materials. Various blends of these base fluids have been formulated into greases to obtain optimum lubricity, thermal stability and good low temperature characteristics.

A number of silicone oils were heat treated with a wide range of metal salts in an effort to improve one or more of the above properties. Greases prepared from the treated fluids did not show any significant improvement over those greases made with the untreated base fluids.

The incorporation of commercially available extreme pressure additives resulted in excessive corrosion at high temperatures. In order to meet the heavy load-carrying requirements, a new class of extreme pressure additives has been developed based on pentachlorobenzene thiol and pentachloro-mercapto acetic acid and their respective derivatives.

Several of these derivatives in 3 to 6% concentration tripled the load-carrying capacity of silicone and silicone-ester base fluid greases as shown by Mean Hertz Load values as high as 98.

WADC TR 58-288 Pt II
ASTIA Document No. AD 214615

May 1959

SUBJECT: DEVELOPMENT OF HIGH TEMPERATURE HEAVY LOAD-CARRYING GREASES
INVESTIGATOR: Robert K. Smith
William Eismann, Jr.
CONTRACT: AF 33(616)-5156
CONTRACTOR: E. F. Houghton & Company
ABSTRACT: The purpose of this study was to develop high temperature greases capable of lubricating heavily loaded surfaces moving against each other in sliding, oscillatory, rolling and rotational motion. Examples of such surfaces are found in actuators, gimbal rings, rocket devices, control mechanisms, hinge pins and rod end bearings.

The development of an extreme pressure grease with a -65°F

to 425°F operating capability was completed. Two arylurea thickened greases have successfully completed all the parameter screening tests. One grease contains a methyl phenyl silicone base fluid while the other has a blended base fluid of a methyl phenyl silicone with a high molecular weight ester oil. Pentachlorophenyl mercapto acetic acid is the extreme pressure additive utilized in both greases. Functional testing is now being conducted in heavily loaded bearings and actuators.

Work was initiated to obtain extreme pressure grease systems capable of operating in the temperature ranges of -40 to 500°F and 0 to 600°F. Presently there is no oil commercially available which will operate successfully for prolonged periods at temperatures above 450°F. There are, however, several experimental fluids which show promise for high temperature use in the near future. Various silicone, ester and mineral type oils with relatively low volatility and high flash points were employed to evaluate the thickening ability of the experimental high temperature materials. The following types of materials were investigated for use as high temperature grease thickeners - graphite, urethanes, imidazolidines and imides of both aromatic and aliphatic dibasic acids. One type of thickener developed - the aluminum complex of pyromellitimides - has melting points above 900°F and shows excellent thickening properties.

WADC TR 58-350
ASTIA Document No. AD 203388

October 1958

SUBJECT: DEVELOPMENT OF GREASES FOR HIGH SPEED BALL AND ROLLER BEARINGS
INVESTIGATOR: Paul R. McCarthy
Guy C. Blewett
Joseph J. McGrath
CONTRACT: AF 33(616)-5020
CONTRACTOR: Gulf Research & Development Company
ABSTRACT: Performance life of ten greases approved under Specifications MIL-L-7711, MIL-G-3278 or MIL-L-3545 was determined in a modified Pope Spindle Tester at 20,000 rpm. and at the temperatures shown below:

| <u>TYPE OF GREASE</u> | <u>TEST TEMPERATURES, °F.</u> |
|-----------------------|-------------------------------|
| MIL-L-7711 | 250 and 350 |
| MIL-G-3278A | 250 and 350 |
| MIL-L-3545 | 300 and 350 |

The general compositions of the specification greases evaluated are as follows:

| <u>TYPE OF GREASE</u> | <u>GENERAL COMPOSITION</u> |
|-----------------------|----------------------------|
| <u>MIL-L-7711</u> | <u>Fluid Component:</u> |

MLG 57-233(a)
MLG 57-234(b)

(a) Polyalkylene glycol
(b) Petroleum Oil
Thickener:
(a) Lithium soap
(b) Sodium-Calcium soaps

MIL-G-3278
MLG 57-235(a)
MLG 57-236(b)
MLG 57-237(c)
MLG 57-238(d)

Fluid Component:
(a) Diester
(b, c and d) Diester-
Petroleum Oil
Thickener:
(a, b, c and d)
Lithium soap

MIL-L-3545
MLG 57-239(a)
MLG 57-240(b)
MLG 57-241(c)
MLG 57-242(d)

Fluid Component:
(a, b, c and d)
Petroleum Oil
Thickener:
(a) Lithium soap
(b, c and d) Sodium soap

Consistency, dropping point, oil separation, evaporation, shear stability and oxidation stability tests were run on the same greases in an attempt to correlate properties of the greases determined by such tests with performance life in bearings.

Both commercially obtainable as well as new experimentally prepared fluids and thickeners were evaluated as components for improved high temperature greases. Of the fluids, the silicones showed the best thermal stability; 5,5-diphenylhydantoin proved to be the best thickener. Experimental greases containing combinations of silicones and 5,5-diphenylhydantoin, in general, gave the longest performance life at 400°F. and 20,000 rpm. All experimental greases, however, failed to consistently meet the target requirement of 500 hours minimum life under the foregoing conditions. The longest single run (891 hours) at 400°F. and 20,000 rpm. was obtained with an arylurea grease "RLG 216-54".

A high speed bearing test ring, believed to be capable of operating under the following conditions, was designed:

Speed: DN value of 0.9×10^6 using ball bearings of 20 and 25 mm. bore

Temperature: Ambient to 600°F.

Radial Load: Up to 75% of the rated capacity of the bearings in the test section at the maximum speed of 45,000 rpm.

HYDRAULIC FLUIDS

WADC TR 56-168 Pt III
ASTIA Document No. AD 213606

May 1959

SUBJECT: SILICONE FLUID RESEARCH FOR THE DEVELOPMENT OF HIGH TEMPERATURE HYDRAULIC FLUIDS AND ENGINE OILS
INVESTIGATOR: Edgar D. Brown, Jr.
Norman G. Holdstock
J. Merle Nielsen
CONTRACT: AF 33(616)-5118
CONTRACTOR: General Electric Company
ABSTRACT: The past year's work has been concentrated on both thermally stable fluids and improved oxidative stability. The most promising materials for thermal stability were the silphenylene polysiloxane fluids. They show no siloxane rearrangement as more conventional silicone fluids do and have stabilities up to the temperature range of 800 - 850°F. Polymer modifications gave good low temperature properties indicating a wide fluid range. Evaluation of various types of oxidation inhibitors showed that iron type additives still do the best inhibiting of silicone fluids. A new processing of 81644 has produced a fluid which is clear at room temperature and does not sludge after prolonged exposure at 500°F.

WADC TR 57-119 Pt II
ASTIA Document No. AD 155712

July 1958

SUBJECT: DEVELOPMENT OF A HYDROLYTICALLY STABLE HIGH TEMPERATURE HYDRAULIC FLUID
INVESTIGATOR: Robert L. Peeler
Steve A. Kovacich
CONTRACT: AF 33(616)3476
CONTRACTOR: California Research Corporation
ABSTRACT: This report covers the second year's work on a contract to improve the hydrolytic stability of silicate ester hydraulic fluids for operation in the -65°F to 400°F temperature range.

Significantly improved hydrolytic stability was found for the following classes of compounds: (1) tetraalkoxysilanes containing two or three tert-butoxy groups; (2) alkyltrialkoxysilanes containing alkyl groups higher than methyl and one tertiary alkoxy group; (3) hexaalkoxydisiloxanes containing four tertiary alkoxy groups; and (4) dialkyltetraalkoxydisiloxanes containing two tertiary alkoxy groups with the alkyl groups preferably ethyl or higher. Compounds which hydrolyzed at 400° F but which did not form significant quantities of insolubles were (1) alkyltrialkoxysilanes con-

taining ethyl or higher alkyl groups and (2) dialkyltetraalkoxydisiloxanes containing ethyl or higher alkyl groups. Glycol silicates, trisiloxanes, and disilylethane derivatives did not show the required hydrolytic stability. Considering all known properties of these compounds, 1, 3-diethyl-1, 1, 3, 3-tetra(2-ethylhexoxy) disiloxane was chosen as the best available base stock for the final hydraulic fluid.

Rate studies with H_2O^{18} showed that the siloxy groups were more easily hydrolyzed than the corresponding alkoxy groups, indicating a limitation of the polysiloxane structure.

Formulation work on the best disiloxane base stock led to a choice of low viscosity methyl phenyl silicone as V.I. improver and isodecyl pelargonate as rubber plasticizer. The new formulations tested greatly exceeded 8515 fluid in hydrolytic stability and had better shear stability. Oxidation stability was poorer, indicating need for further formulation work on oxidation inhibitors. Other properties tested were comparable to 8515 fluid.

WADC TR 57-151 Pt II
ASTIA Document No. AD 210715

March 1959

SUBJECT: RESEARCH ON THE FLAMMABILITY CHARACTERISTICS OF
AIRCRAFT HYDRAULIC FLUIDS - Part II. Explosion
Hazards of Aircraft Hydraulic Fluids and Fuels

INVESTIGATOR: Michael G. Zabetakis
George S. Scott
Agnes C. Imhof
Sotirois Iambiris

CONTRACT: DO (33-616) 57-4

CONTRACTOR: Bureau of Mines

ABSTRACT: The results of limit of flammability and spontaneous ignition temperature tests conducted on six high density fuels and JP-6 are presented. The former tests were conducted at atmospheric pressure and elevated temperatures and the latter at reduced and elevated pressures with the fuels in contact with pyrex and stainless steel surfaces in air and oxygen. In addition, spontaneous ignition temperature tests were conducted at atmospheric pressure on seven hydraulic fluids in oxygen and oxygen-enriched air with the fluids in contact with a pyrex surface. All tests were conducted by members of the Branch of Gas Explosions, Division of Explosives Technology, U. S. Bureau of Mines between 10 December 1957 and 30 June 1958. Monoisopropylbicyclohexyl (HTF-27), monoisopropylbiphenyl (HTF-28), tetralin (HTF-30), bicyclohexyl (HTF-31), decalin (HTF-32), and methylcyclopentadiene (HTF-33), and hydraulic fluids Esso Univis J-43 (Spec. MIL-H-5606A), MLO 53-446 (General Electric GE 81406), MLO 54-540 (Monsanto OS45), MLO 54-581, MLO 54-645 (85% Oronite 8200 + 15% Plexol), MLO 54-856 (Hollingshead 72073C) and MLO 8200 (Oronite 8200) were tested.

September 1958

SUBJECT: DEVELOPMENT OF HIGH TEMPERATURE OXIDATION-CORROSION
INHIBITORS TO IMPROVE STABILITY OF HIGH TEMPERATURE
HYDRAULIC FLUIDS AND LUBRICANTS

INVESTIGATOR: Robert Brunier

CONTRACT: AF 33(616)-5101

CONTRACTOR: Armour Research Foundation

ABSTRACT: The objective of this research program was to synthesize and evaluate selected organic compounds as high temperature oxidation - corrosion inhibitors in mineral oils, synthetic ester lubricants, and silicone and silane fluids. As a result of this and continued studies, specific inhibitors will be recommended for use.

During this 12-month period, known inhibitors were appraised and rated. On the basis of this appraisal, organic structures and functional groups effective in corrosion inhibition were determined and organic molecules incorporating these structures and groups designed to overcome the limitations found in known inhibitors. The synthesis of the selected compounds was started.

Simultaneously, outside sources were checked for compounds not yet tested as oxidation-corrosion inhibitors, and some of these compounds were selected for screening. These selections were made on the basis of structures related to those found to be effective by the appraisal program and also structures with potential use as inhibitors.

The compounds were evaluated by a micro oxidation-corrosion test developed at Wright Air Development Center. The testing was directed mostly toward evaluating additives in silane and ester base fluids. Compounds on hand were first submitted to a screening test, followed by specification testing of the most promising compositions.

Some of the compositions evaluated were very active in the silane fluids, and the specifications for a 500-700°F lubricant can probably be filled by such mixtures. Specifically, a mixture of 1,10-diaminodecane and isonicotinic acid thionamide and a mixture of 1,10-diaminodecane, isonicotinic acid thionamide, and triphenylarsine were the most effective inhibitors in the silane fluid. No composition tested in the ester was more active than the ester alone, and more work will have to be done to stabilize this lubricant for use above 500°F.

January 1959

SUBJECT: SYNTHESIS AND EVALUATION OF HIGH TEMPERATURE
ANTIOXIDANTS FOR SYNTHETIC HYDRAULIC FLUIDS
AND LUBRICANTS

INVESTIGATOR: R. M. Silverstein

CONTRACT: AF 33(616)-5276

CONTRACTOR: Stanford Research Institute

ABSTRACT: During the period covered by the current report, candidate antioxidants have been screened in the following lubricating fluids: F-50 silicone fluid, paraffinic mineral oil MLO 57-574, silane fluid MLO 57-461, silane fluid MLO 57-628, and naphthenic mineral oil MLO 57-573.

A number of additives at 0.2% concentration were found to be effective in retarding high temperature oxidative degradation (i.e. gelation) of F-50 silicone oil. Condensed aromatic ring structures containing three or more rings were effective as a class.

Several of the effective additives were soluble enough in F-50 silicone fluid at low temperatures to warrant their consideration for practical use. Fluoranthene at 0.2% concentration, for example, did not come out of solution at -65°F. Solubility studies are still in progress. A mechanism study was initiated to determine how condensed aromatic ring structures inhibit gelation of F-50 silicone fluid.

Following the lead uncovered by the effectiveness of N-phenylferrocene-carboxamide, a number of ferrocene derivatives were prepared and evaluated. None of these compounds showed pronounced antioxidant activity.

None of the additives evaluated to date showed any antioxidant activity in the silane fluids or in the mineral oils.

JOINING

WADC TR 58-479
ASTIA Document No. AD 208323

February 1959

SUBJECT: RESEARCH AND DEVELOPMENT OF PROCEDURES FOR
JOINING OF SIMILAR AND DISSIMILAR HEAT-RESISTING
ALLOYS BY ULTRASONIC WELDING

INVESTIGATOR: Norman E. Weare
John N. Antonevich
Robert E. Monroe
David C. Martin
CONTRACT: AF 33(616)-5342
CONTRACTOR: Battelle Memorial Institute
ABSTRACT: An investigation was conducted to apply ultrasonic welding to joining similar and dissimilar heat-resisting alloys and to study the fundamentals of this process.

Ultrasonic spot welds were made in various combinations of heat-resisting alloys. Room temperature tension-shear and cross-tension strengths were obtained for each combination. Metallographic examinations of the heat-resistant weldments showed in presence of cracks at the edges of many of the spot welds. This cracking is probably caused by high cyclic stresses at the edge of the weld producing fatigue failures in this area. Methods of preventing such cracking can probably be determined.

Efforts in the fundamental studies were aimed at studying the mechanism of bonding by ultrasonic welding. Effects of times, temperatures, and forces involved or closely related to bonding were determined although the exact mechanism was not established. Also determined were the effects of factors associated with the process and materials involved.

LUBRICANTS

WADC TR 54-576 Pt III
ASTIA Document No. 155518
OTS Release

May 1958

SUBJECT: EFFECT OF METALS ON LUBRICANTS
INVESTIGATOR: John B. Christian
ABSTRACT: This report shows the effects which an ester and a disiloxane have on various metals, and the effects which those metals simultaneously have on the fluids at elevated temperature (550°F). The disiloxane proved to be compatible with all of the metals tested, while the ester showed signs of being generally incompatible with all of the metals under the test conditions.

December 1958

SUBJECT: THE EFFECT OF METALS ON LUBRICANTS
INVESTIGATOR: John B. Christian
ABSTRACT: The qualitative effects which several aircraft fluids and lubricants have on the surface of various metals at room temperature and at 400°F for periods up to 528 hours are reported.

Sixteen different metals were cut into one-inch square specimens and stored with aircraft fluids and lubricants in capped bottles under the above conditions. Each was observed at the end of 48 and 96 hours, and every 72 hours thereafter until the end of 528 hours.

Qualitatively, all metals, with the exception of lead, and fluids were compatible at room temperature up to 528 hours, but at 400°F compatibility generally ceased at 384 hours.

June 1958

SUBJECT: FLUIDS, LUBRICANTS, FUELS AND RELATED MATERIALS
INVESTIGATOR: E. Erwin Klaus
Merrell R. Fenske
CONTRACT: AF 33(616)-2851
CONTRACTOR: Pennsylvania State University
ABSTRACT: This report describes work carried out on a continuing project directed toward the development of improved hydraulic fluids and jet engine lubricants for use in the high temperature range of 400° to 700°F. bulk oil temperatures. With few exceptions these studies are equally applicable to hydraulic fluid and jet engine oil development.

Extensive laboratory evaluation studies are presented for a series of mineral oils and hydrocarbons which have been super-refined by a pilot plant hydrogenation over nickel catalyst. Advantages of hydrogenated and exhaustively acid-refined mineral oils and hydrocarbons over conventionally refined mineral oils are demonstrated for application as base stocks for hydraulic fluids and lubricants. Completed hydraulic fluid formulations containing antifoam, antioxidant, and lubricity additives and jet engine oil formulations containing, in addition to these three additives, Acryloid and paraffinic resin dispersants are described. A silane, several esters, Spec. MIL-L-7808 fluids, and an improved lubricity silicone hydraulic fluid are evaluated critically in high temperature tests.

Properties of used samples of several jet engine oils evaluated in the J-57 jet engine are presented. These samples indicate more

fluid deterioration than is predicted by Spec. MIL-L-7808 type stability tests. Several more severe oxidative tests, including the Petroleum Refining Laboratory thin film oxidation test and the isothermal and non-isothermal successive oxidation tests are described. These tests are designed to simulate more nearly the severity encountered in the J-57 engine test.

The effects of several variables, including fluid type, fluid molecular weight, additives, fluid flow rate, and air flow rate, on the high temperature single-pass lube rig are illustrated. Procedures for the analysis of exhaust gas from the single-pass lube rig have been established to place oxidation encountered in this test on a quantitative basis.

Bulk oil oxidation tests of high temperature fluids are shown for test temperatures of 347°, 500°, and 700°F. The effect of fluid type and mineral oil class, degree of refining, and molecular weight are discussed for the 700°F. tests. An evaluation of the character of the volatile products of the 700°F. oxidation tests is presented.

Wear and lubrication studies in the four-ball testers are used to illustrate the additive effects of silicones, silicates, thiocarbamates, and diisopropyl acid phosphite in ester and mineral oil fluid types.

Panel coker data in the Model C and controlled atmosphere units are compared and summarized for the effects of fluid type, degree of refining, molecular weight, and additives.

The construction of an evaporation unit of the type used in the Federal Test Method Standard No. 791 is described.

Some additional miscellaneous duties have been performed at the request of the Wright Air Development Center. These duties include: (1) distribution of Laboratory reports, (2) formulation of fluids, (3) distribution of standard fluid samples and, (4) evaluation of specific fluid properties.

WADC TR 56-370 Pt III
ASTIA Document No. AD 155856

August 1958

SUBJECT: RESEARCH IN HIGH TEMPERATURE BEARING LUBRICATION
IN THE ABSENCE OF LIQUID LUBRICANTS
INVESTIGATOR: R. A. Coit
S. S. Sorem
R. L. Armstrong
C. A. Converse

CONTRACT: AF 33(616)-2999
CONTRACTOR: Shell Development Company
ABSTRACT: A method of operating rolling contact bearings at high temperatures without using conventional liquid lubricants has been evolved. This method employs a "protective atmosphere" around the bearing. The atmosphere has two functions, the prevention of the formation of abrasive oxides at the bearing surfaces and the formation, by reaction with the bearing surfaces, of antiscuffing films to prevent catastrophic wear at sliding contacts. Factors involved in the selection of atmosphere compositions and bearing materials for use with this method of operation are discussed. Test operations which have demonstrated the performance of this system at various temperatures from 600 to 1000°F are described.

WADC TR 57-36 Pt II
ASTIA Document No. 155726
OTS Release

July 1958

SUBJECT: AIRFRAME LUBRICANTS - Part II. Development of a Laboratory Technique for Determining Rust-Preventive Properties of Lubricating Greases
INVESTIGATOR: Airframe Lubricants Group
CONTRACT: AF 33(616)-2888
CONTRACTOR: Coordinating Research Council, Inc.
ABSTRACT: This final report on rust-preventive properties of lubricating greases describes the work of CRC laboratory and service evaluation panels in their objective to develop test techniques for predicting the performance in actual service of airframe and accessory lubricants. A description is included of the three test techniques developed and the reasons for ultimately recommending one of them, the Research Technique for Determining Rust-Preventive Properties of Lubricating Greases in the Presence of Free Water (CRC Designation L-41-957).

WADC TR 57-61 Pt II
ASTIA Document No. AD 155564
OTS Release

May 1958

SUBJECT: LUBRICATION OF TITANIUM
INVESTIGATOR: Nicholas Fatica
CONTRACT: AF 33(616)-3350
CONTRACTOR: Clevite Research Center
ABSTRACT: This investigation sought to obtain some information about the frictional properties of modified titanium coatings and to make a comparison of the wear resistance of the best surface treatments in the presence of

various lubricants using the Shell Four-Ball Wear Tester and the Falex Tester.

It has been found that systems showing high wear rates in one tester will also show high wear rates in the other. If wear is expressed as volume or weight loss (W), it may generally be correlated with load (L) and time (t) by an expression of the form $W = KLt$ for either tester. The constant K includes the characteristics of the machine, the nature of the specimens and the nature of the lubricant. It is concluded that the essential nature of the action taking place in either tester is identical and that therefore any lack of correlation must be attributed to operation in widely different pressure and temperature ranges.

The correlation of wear rates with the frictional characteristics of the different systems was attempted in both testers with moderate success.

The reproducibility of the results for various systems is too poor to permit differentiating between the different titanium base alloys used in any particular treatment. As for the various surface treatments investigated, it appears that it is possible to obtain equivalent wear resistance in many cases using electroless nickel plates, cyanided, nitrided, carburized, oxidized, or carburized iron-plated titanium. Of these, oxidized and electroless nickel plated titanium fail at high loads. The use of conventional lubricants for any but electroless nickel and carburized iron-plated titanium is unreliable. Halogenated materials appear to be the best lubricants for the other treatments. It has been shown that the higher the halogen content of the lubricant, the better its lubricating properties.

Resin-bonded coatings fail at higher test temperatures.

WADC TR 57-177 Pt II
ASTIA Document No. AD 155862

August 1958

| | | |
|---------------|--|-------------------|
| SUBJECT: | ENGINE OIL DEVELOPMENT | |
| INVESTIGATOR: | C. Lynn Mahoney | William W. Kerlin |
| | Emmett R. Barnum | Karl J. Sax |
| | W. S. Saari | P. H. Williams |
| CONTRACT: | AF 33(616)-3182 | |
| CONTRACTOR: | Shell Development Company | |
| ABSTRACT: | Conventional ester and petroleum hydrocarbon based lubricants, depending on inhibitors for resistance to oxidation, are very sensitive to radiation damage and lack sufficient stability for high temperature use. Selected aromatic compounds, designed for stability in absence of inhibitors, appear to be capable of withstanding considerably higher temperatures and radiation levels than present oils. Aromatic esters, car- | |

bonates, silanes and polyphenyl compounds have been investigated but polyphenyl ether derivatives have shown the greatest over-all promise.

The unsubstituted polyphenyl ethers are very stable materials. They undergo little change in oxidation-corrosion tests at 500°F and form only small amounts of coke in panel coke tests at 900°F. Their initial thermal decomposition temperatures are over 800°F. Physical property changes are moderate at radiation levels of 10^9 rad. Their wear characteristics are very much better than most other classes of highly aromatic compounds.

Alkyl substituents generally lower the melting points of polyphenyl ethers but only carefully selected groups, such as the *Q*-cumyl- and tertbutyl-, can be used without seriously affecting the stability. These alkyl-substituted polyphenyl ethers are not as stable as the corresponding unsubstituted ethers but undergo little change in 475°F oxidation-corrosion tests, form little coke at 800°F and have initial thermal decomposition temperatures of 700 to 770°F. Physical property changes in these alkyl substituted polyphenyl ethers are also moderate at radiation levels of 10^9 rad but radiation greater than 2.5×10^8 rad seriously lowers their resistance to oxidation.

Several methods of lowering the melting points of polyphenyl ethers are being investigated at the present time. Initial results with isomerization procedures have been very promising. Several stable liquid alkyl substituted ethers have been prepared. Additional work with alkyl derivatives is planned and some effort is being made to lower the melting points of unsubstituted ethers through use of isomerization reactions.

WADC TR 57-255 Pt II
ASTIA Document No. AD 155736

July 1958

SUBJECT: NUCLEAR RADIATION RESISTANT TURBINE ENGINE
LUBRICANTS
INVESTIGATOR: Alfred H. Matuszak
CONTRACT: AF 33(616)-3181
CONTRACTOR: Esso Research and Engineering Company
ABSTRACT: Work performed under Contract No. AF 33(616)-3181 on the development of radiation resistant turbine engine lubricants for possible use in aircraft nuclear power plants is described. This is a continuation of work reported in WADC TR 57-255 and completes the screening and evaluation of over one hundred mineral and synthetic materials consisting of finished lubricants (Phase I) and inhibited lubricant base stocks (Phase II). These materials were irradiated at the MTR and at

Hanford under static conditions using a screening dosage of about 10^{10} ergs/gm C (10^8 roentgens) and a dose rate of about 3×10^7 ergs/gm C/hr. Extended irradiations were done at 5 and 10×10^{10} ergs/gm C on the more promising lubricants.

In the Phase I work finished mineral oils generally showed greater retention of original lubricant properties at 10^{10} ergs/gm C than did the finished synthetic oils. Of the mineral oils investigated a Paraffinic Grade 1065 Aviation Oil meeting MIL-L-6082B requirements but inhibited with phenyl-alpha-naphthylamine was the most promising. Foaming was a problem at 10^{10} ergs but not at higher dosages. Lubricant degradation in general was more severe, however, at the higher levels. The most serious deficiencies resulting from the irradiation of the Grade 1065 oil over the range 10^{10} to 10^{11} ergs/gm C were its viscosity increase and flash point decrease. Metal corrosion was negligible. Overall, the Grade 1065 Aviation Oil is indicated to possess reasonably good resistance to radiation under static conditions to dosages between 10^{10} and 5×10^{10} ergs/gm C, and if viscosity and flash point are not limiting, to possibly 10^{11} ergs/gm C. Although the changes noted are not considered excessive except for viscosity increase and flash point, dynamic in-source testing will be necessary to establish the usefulness of this oil as a nuclear powered aircraft lubricant.

In the Phase II mineral base stock work wherein 19 base stocks or blends were screened during the second year an inhibited paraffinic base stock looked the most attractive. It paralleled very closely the performance of the Paraffinic Grade 1065 Aviation Oil. Hydrogenation of this as well as a more viscous paraffinic bright stock did not effect improvements in stability toward radiation and oxidation. The addition of stable aromatic base stocks to the paraffinic base resulted in several expected improvements. As in the case of the Grade 1065 Oil, dynamic testing will be required to evaluate this oil further. Other stable base stocks were Kenflex B and Philrich 5. These are viscous aromatic hydrocarbon oils which may be useful as blend components with other attractive oils.

In the more recent Phase I work on "finished" synthetic oils thirteen blends newly formulated from attractive base stocks and a MIL-L-25336 approved oil were screened as possible Phase II type oils. Three oils showed promise. Two of these were di-octyl sebacate based oils containing Plasticizer HM (an aromatic polyester) as a stabilizer against radiation. One contained TCP. These showed moderately good radiation and oxidation stability at the 10^{10} ergs/gm C. Radiation at higher dosages unfortunately was not carried out. This will be necessary to determine their value as more stable radiation resistant lubricants. The third oil, an all aromatic blend containing Cabflex HS-10 and Kenflex B, likewise showed good

radiation and oxidation stability. It is comparable with the paraffinic mineral oils in many respects. It shows less viscosity change but tends to be slightly corrosive as a result of the greater acidities developed only during higher radiation dosages.

In the Phase II base stock evaluation program aromatic esters were generally more stable than aliphatic diesters, complex esters, glycols or polyalkylene glycol monoethers. Of the thirty synthetic base stocks screened in the more recent work Cabflex HS-10 (an alkyl-aryl phthalate), isodecyl naphthalate and Plasticizer HM were the most stable. Although these materials showed less viscosity increase than the mineral oils they exhibited somewhat greater changes in flash point, acidity and corrosivity. The changes noted after irradiations up to 5×10^{10} ergs/gm C would not be considered prohibitive however as far as lubricant performance is concerned. Some question would arise as to their usefulness at 10×10^{10} ergs/gm C, however.

It is recommended the oils mentioned above be further evaluated in dynamic in-source tests to more clearly define their usefulness as radiation stable lubricants.

WADC TR 57-299 Pt II
ASTIA Document No. 155591

May 1958

SUBJECT: NUCLEAR RADIATION RESISTANT LUBRICANTS
INVESTIGATOR: William L. R. Rice, 1/Lt., USAF
ABSTRACT: This report presents a summary of current information on the state of the art of nuclear radiation resistant lubricant development. Data are presented on the effects of gamma radiation on a number of commercial fluids and lubricants, with a discussion of potential problem areas. Advanced materials for extremely high temperatures and radiation exposures are discussed, and the present status of preferred lubricants is outlined.

Of the new base materials for use in extreme conditions of temperature and radiation, the polyphenyl ethers show the most promise. Relatively low melting compounds can be prepared that undergo minor change in 500°F oxidation-corrosion tests and form little coke at temperatures as high as 800°F. Stability during in-source oxidation-corrosion tests has been shown to be good. The major drawback to use of the polyphenyl ethers is their low temperature limitation. At present, the majority of these materials melt at temperatures in the range 100°F to over 200°F.

WADC TR 57-455 Pt II
ASTIA Document No. 203121

October 1958

SUBJECT: HIGH TEMPERATURE SOLID DRY FILM LUBRICANTS
INVESTIGATOR: Melvin T. Lavik
CONTRACT: AF 33(616)-3684
CONTRACTOR: Midwest Research Institute
ABSTRACT: Solid dry film lubricants appear to be the answer for many high temperature lubrication problems. However, the wear-life of these films is dependent upon a large number of factors which complicate the choice of a particular lubricant film and its proper application. This report describes three phases of work directed toward the development of high temperature solid dry film lubricants.

1. Parametric study of wear-life factors: The fractional factorial design of experiments (total of five) is used to evaluate the effect of ten factors upon the wear-life of several solid film lubricants. The factors studied are environmental temperature, bearing load, substrate hardness, film thickness, relative linear surface speed, lubricant material, film binder, lubricant-to-binder ratio, type of motion, and geometry of rub shoe. In the range of values investigated, the temperature (400-550°F) and the load (10,000 to 65,000 psi) had the greatest effect upon the wear-life of the lubricant films. Although the results are limited, a procedure is developed for evaluating a lubricant (for a particular application) with a minimum number of tests.

2. Nuclear radiation effects: Four commercial solid dry film lubricants were submitted to gamma and neutron irradiation. Three of the films were resin-bonded mixtures of graphite and molybdenum disulfide. The other film was a mixture of lead oxide and graphite bonded with a glass-like material. Only the gamma irradiated specimens have been tested. The wear-life of one lubricant film is possibly affected by gamma irradiation; the others showed no significant effect.

3. Search for high temperature lubricants: A group of 16 inorganic materials have been selected for further investigation as possible high temperature (800°F) lubricants. This selection was made on the basis of a literature survey and the present knowledge of lubrication mechanisms. These materials are simple compounds and are mostly sulfides, oxides and chlorides of metals occurring in periods 3, 4, or 6 of the periodic table.

WADC TR 57-773
ASTIA Document No. AD 155670

June 1958

SUBJECT: EVALUATION OF HIGH TEMPERATURE GEAR AND SPLINE
LUBRICANTS

INVESTIGATOR: Donald J. Fessett
Charles W. Sauter
CONTRACT: AF 33(616)-3539
CONTRACTOR: Western Gear Corporation
ABSTRACT: The load carrying ability of three lubricants, Dow Corning XF-258, General Electric Versilube F-50, and MIL-L-7808, was determining on spur and helical gears. Tests were conducted on 2.000 inch gears at speeds from 2500 rpm to 15,000 rpm and inlet lubricant temperatures from 165° to 700°F.

This report includes the results of these tests displayed in graph and table form, a discussion of these results, and conclusions. Also included in this report are test results previously obtained from WADC Universal Gear and Spline Lubricant Tester and the operating procedure to be used on the evaluation of gear and spline lubricants at high temperatures.

WADC TR 57-773 Pt II
ASTIA Document No. AD 214614

May 1959

SUBJECT: EVALUATION OF HIGH TEMPERATURE GEAR AND SPLINE LUBRICANTS
INVESTIGATOR: Donald J. Fessett
CONTRACT: AF 33(616)-5631
CONTRACTOR: Western Gear Corporation
ABSTRACT: The load carrying abilities of the following seven lubricants were determined on 16-pitch 2.000 in. pitch diameter spur gears:

Octadecyl tri(decyl)silane
MLO 57-426 -- Pentaerythritol tetracaproate
MLO 58-431 -- 10% silicone, 90% pentaerythritol tetracaproate
MLO 7379 -- Super refined bright stock
MLO 7380 -- Super refined paraffinic neutral
MLO 7381 -- Super refined paraffinic neutral with
0.2% alkyl acid phosphite
MLO 7383 -- Super refined naphthenic mineral oil

Tests were conducted at speeds up to 20,000 rpm and lubricant temperatures to 600°F. Octadecyl tri(decyl) silane lubricant exhibited the best load carrying ability of 2500 lb/in. of face width at 10,000 rpm and 600°F. MLO 58-431 and MLO 7379 ranked second and MLO 7381 third in overall mechanical performance. MLO 7383 scored at a higher load at 600°F than at 400°F. The load carrying ability of MLO 57-426 decreased the greatest with increasing temperature from 400 to 600°F.

Modifications made on the Universal Gear and Spline Tester included a more efficient test lubricant heating system, a tempera-

ture controller and recorder, an electronic speed indicator and an optical system. Operating procedure of the modified tester is included in the appendix.

WADC TR 58-15
ASTIA Document No. AD 155870

September 1958

SUBJECT: THE EFFECT OF STRUCTURE OF POLYHYDRIC ALCOHOL
ESTERS ON THEIR SUITABILITY AS HIGH TEMPERATURE
LUBRICANTS

INVESTIGATOR: Harold W. Adams
William L. R. Rice

ABSTRACT: The research and development effort discussed in this report concerns the feasibility of using esters of the neopentyl type as lubricants up to 400° to 500°F.

The absence of the beta hydrogen on the alcohol moiety has, in previous investigations, resulted in superior thermal stability of the esters of such alcohols. This increase in thermal stability appears to be in the range of approximately 100°F. This is accomplished by forcing thermal degradation to proceed through free radical formation.

Although these neopentyl type esters have improved thermal stability over conventional diester blends, they do not necessarily possess superior oxidation stability. The use of neopentyl type ester fluids in an oxidizing environment at 400° or 500°F will definitely depend upon the development of an efficient oxidation inhibitor.

The over-all assessment of the chemical and physical properties of the neopentyl type ester fluids shows considerable promise for high temperature application.

WADC TR 58-248
ASTIA Document No. AD 206669

December 1958

SUBJECT: INVESTIGATION OF NEOPENTYL POLYOL DERIVATIVES
AS BASE FLUIDS FOR HIGH TEMPERATURE TURBINE
ENGINE OILS

INVESTIGATOR: Adolph J. Deinet

CONTRACT: AF 18(600)-1667

CONTRACTOR: Hayden Newport Chemical Corporation

ABSTRACT: Forty-four esters, ether esters, and polyesters based on hexa, tetra, tri, and di methylol neopentyl alcohols were prepared. Of these, twenty were submitted to Wright Air Development Center for bench screening.

This report tabulates data obtained on these compounds.

WADC TR 58-283
ASTIA Document No. 203642

October 1958

SUBJECT: MEASUREMENT OF VISCOSITIES OF GAS-TURBINE LUBRICANTS
AT ELEVATED TEMPERATURES AND PRESSURES

INVESTIGATOR: Jack S. Barr

CONTRACT: AF 33(616)-3900

CONTRACTOR: Southern Research Institute

ABSTRACT: A high-pressure viscometer to measure the viscosities of some aircraft lubricating oils at elevated temperatures and pressures was constructed. The equipment was calibrated, but viscosities of the various oils will be determined on a subsequent contract.

A maximum pressure of 188,000 psi was obtained during a test of the equipment. The apparatus was designed for tests at temperatures from ambient to 400°F.

WADC TR 58-297
ASTIA Document No. 203382

October 1958

SUBJECT: DEVELOPMENT OF EVALUATION TECHNIQUES FOR DETERMINATION
OF THE LUBRICITY AND STABILITY OF NEW HIGH-TEMPERATURE
LUBRICANTS AND HYDRAULIC FLUIDS

INVESTIGATOR: Vernice Hopkins
Andrew D. St. John

CONTRACT: AF 33(616)-5202

CONTRACTOR: Midwest Research Institute

ABSTRACT: A Shell four-ball wear tester has been modified for operation up to 800°F. A lubricant circulating system was included in the modification, and comparable noncirculating and circulating lubricant evaluation programs were completed. Silicone fluids and silanes neat and with anti-wear additives, a mineral oil, pentaerthritol ester and disiloxane fluids and lubricants were evaluated at 167°F, 400°F, and 700°F, 10 kg. and 40 kg. loads, and 600 rpm and 1,200 rpm spindle speeds. Wear scar, frictional torque, and wear rate data were recorded. The lubricants have been rated relative to each other by applying the results of a statistical analysis performed on the wear scar data.

A partially completed analysis of the energy dissipation and heat transfer in a roller bearing is reported. The analysis will ultimately provide scaling relations to be used in the design of a bearing temperature stabilization tester. The major simplifying assumptions and results may be listed as follows:

The lubricant is assumed to have constant viscosity and density. Also, the lubricant flow through the rolling-slipping contacts is calculated without consideration of the local body distortions. The friction force which occurs as the result of direct contact between bearing elements is described with a constant coefficient. The extent of the physical contact is dependent on the load carried directly (rather than hydrodynamically) and the statistical description of the surfaces.

Equations of motion for the bearing assembly are formulated for pure hydrodynamic lubrication and for a combination of hydrodynamic and direct contact situations. The equations are solved for the pure hydrodynamic case using the assumption of constant roller and cage speeds. The assumption of constant roller spin is found inadequate for those cases in which sizeable loads are carried by direct contact and no proper solutions for this case are reported.

In preparation for heat transfer calculations, the lubricant streamlines are obtained in a generalized form as are the lines of constant dissipation. The heat transfer problem is introduced.

A survey of machine components which required extreme pressure lubrication was performed. The functional characteristic of these components were compared to the test elements of extreme pressure lubrication testers. As a result of this comparison and the limited operational temperature range of existing testers a new extreme pressure lubricant tester was designed for operation up to 700°F. This new tester possesses more flexibility than existing testers. The test results should correlate better with performance data as the conditions of testing may be selected nearer to the operating conditions of a machine component.

An evaluation facility has been designed in which accessory components may be mounted and used as test rigs for the practical evaluation of lubricants and hydraulic fluids. A variety of types and sizes of components may be tested over a temperature range of -100°F to +800°F. This facility consists of a 5 ft. by 5 ft. by 5 ft. environmental chamber, 50 h.p., 12,000 rpm variable speed, mechanical drive, and AC and DC power supplies for various components.

MATERIALS INFORMATION

WADC TN 58-192

September 1958

WADC TR 53-373 Sup 6

60

SUBJECT: MATERIALS INFORMATION CENTERS
INVESTIGATOR: L/Col M. E. Fields
Mr. D. H. Cartolano

ABSTRACT: Slightly more than one hundred information centers are reported. These centers are engaged in collecting and disseminating information on a variety of materials and hardware. In some cases, access to the information is restricted to members, supporters and government organizations and in other cases information is disseminated to all inquires.

WADC TR 58-655

December 1958

OTS Release

SUBJECT: AIR RESEARCH AND DEVELOPMENT COMMAND TECHNICAL
SYMPOSIUM 9-10 JULY 1958 - Statler-Hilton Hotel,
Dallas, Texas

ABSTRACT: In perhaps no other period of recorded history has the attention of the world's peoples been more closely focussed upon the endeavors of the scientific community than they are today. In exchange for this newly-acquired fame, the men of science have responded to an astounding degree. Without a doubt, the most singular event they have precipitated is the birth of the Space Age - the opening of a vast new frontier whose possibilities, like its dimensions, are limitless.

The exploration of the immensity of space will call upon vehicles and propulsion systems with characteristics previously believed unattainable. All of the classes of materials which combine to make up these vehicles and their attendant systems must function reliably and durably within an atmosphere alien to that known during their terrestrial life. Cosmic radiation, aurorae, meteorite dust, operation in a near-vacuum, the questionable effects of zero-gravity, and a host of other factors in combination represent formidable barriers to long life of space materials. It may truly be said that of all the building blocks which comprise a weapon system, the materials of construction form the keystone.

The problems which confront us in the development of superior materials may best be resolved by a free discussion of ideas and information between representatives of science, industry, and the military services. It is our sincere hope that the technical papers and the panel discussions of this symposium will provide the opportunity for such a mutual interchange.

MATERIALS PHYSICS

WADC TR 56-222 Pt II
ASTIA Document No. AD 202493
OTS Release

October 1958

SUBJECT: DETERMINATION OF EMISSIVITY AND REFLECTIVITY
DATA ON AIRCRAFT STRUCTURAL MATERIALS
PART II - Techniques for Measurement of Total
Normal Emissivity, Normal Spectral Emissivity,
Solar Absorptivity and Presentation of Results

INVESTIGATION: Howard T. Betz
O. Harry Olson
Bert D. Schurin
James C. Morris

CONTRACT: AF 33(616)-3002

CONTRACTOR: Armour Research Foundation

ABSTRACT: Equipment has been designed, constructed and calibrated for the measurement of total normal emissivity in the range -300°F to $+3000^{\circ}\text{F}$. The procedure consists in comparing the total normal radiance of a sample to that of a comparison blackbody, the ratio of the signals being taken as the emissivity. A thermistor detector is used in conjunction with a folded optical system to record the radiation which is chopped at 16 cps.

The normal spectral emissivity values are obtained by an optical pyrometer method which makes use of the relationship between the true temperature of a sample to its apparent brightness temperature. A Leeds and Northrup disappearing filament pyrometer is used to make the necessary measurements.

An integrating sphere reflectometer is used to measure spectral reflectivity in the wavelength range, 0.3 to 3.0 microns. A General Electric Recording Spectrophotometer is used for the visible range and an apparatus of our own design for the ultraviolet and infrared. The latter employs a Perkin-Elmer monochromator, a comparison type integrating sphere, and a lead sulfide cell detector. Spectral reflectivity data are combined with solar spectral energy data to determine solar absorptivity at sea level and above the earth's atmosphere.

WADC TR 56-222 Pt II Sup I
ASTIA Document No. AD 202494
OTS Release

October 1958

SUBJECT: DETERMINATION OF EMISSIVITY AND REFLECTIVITY DATA
ON AIRCRAFT STRUCTURAL MATERIALS
INVESTIGATOR: O. Harry Olson
James C. Morris
CONTRACT: AF 33(616)-3002
CONTRACTOR: Armour Research Foundation
ABSTRACT: Total normal emissivity data are presented for a list of materials which could not be measured with the equipment described in the main body of the report. Instead they were measured with equipment developed subsequently to handle refractories and glasses. In the former, samples were heated by conduction heating in vacuum, in the latter, samples were heated in a tubular furnace in air.

Spectral Reflectivity curves from 0.3 to 2.7 microns are presented for a list of materials and their solar absorptivity values have been calculated.

WADC TR 56-423 Pt II
ASTIA Document No. AD 157169

September 1958

SUBJECT: THERMAL PROPERTIES OF CERTAIN METALS
PART II - Iron, Beryllium, Iridium, Palladium,
Platinum, and Tungsten
INVESTIGATOR: Thomas C. Goodwin, Jr.
Mauree W. Ayton
CONTRACT: DO 33(616)55-10
CONTRACTOR: Library of Congress
ABSTRACT: The bibliography on the thermal properties of certain metals consists of references, with abstracts, to pertinent open literature published from 1920 to 1957, and to unclassified reports issued from about 1944 to 1957. These references were obtained by a comprehensive search of the sources listed in the Introduction. The material included in the bibliography pertains to various thermal properties, namely, heat capacity, thermal conductivity, emissivity, thermal diffusivity, and thermal expansion of iron (pure), beryllium, iridium, rhodium, palladium, platinum, and tungsten.

WADC TR 57-374 Pt IV

October 1957

SUBJECT: PHYSICAL PROPERTIES OF HIGH TEMPERATURE MATERIALS
PART IV - Thermal Diffusivity Apparatus for 100° to
1,500°C
INVESTIGATOR: Howard W. Flieger, Jr.
Defoe C. Ginnings

WADC TR 53-373 Sup 6

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CONTRACT: DO 33(616)56-21
CONTRACTOR: National Bureau of Standards
ABSTRACT: An apparatus has been designed and constructed for measuring diffusivities up to about 1500°C. Values of thermal conductivity may be derived from thermal diffusivity values using density and heat capacity values. The apparatus was designed for measurements on materials having thermal diffusivity values less than 0.1 cm²/sec., such as most refractory oxides at moderate to high temperatures. A radial heat flow method is used, heating the outside of a cylindrical sample at a constant rate and measuring the resulting radial temperature difference. Preliminary tests at moderate temperatures have indicated satisfactory performance in both precision and in ease of operation. The apparatus will be used to measure thermal diffusivities of certain ceramic materials which seem suitable as standards.

WADC TN 57-395
ASTIA Document No. AD 151188
OTS Release

May 1958

SUBJECT: DENSITY MEASUREMENTS FOR SMALL PARTICLES
INVESTIGATOR: Nora E. Srp
ABSTRACT: A method is described for determining the density of small solid objects. A capillary buret is used to draw liquid from a convex meniscus at the top of a small metal cup until the meniscus breaks. The small object is then dropped into the cup and the excess liquid is drawn into the buret until the meniscus breaks again. The difference between the two levels on the buret measures the volume of the material. The weight of the material divided by the volume gives the density of the object in grams per cubic centimeter. These samples were measured at 80° ± 0.5° Fahrenheit. Since standards were not obtained the accuracy was not determined. The expected deviation from the mean for a single determination is ± 0.07 g/cc.

WADC TN 57-413
ASTIA Document No. AD 151189
OTS Release

May 1958

SUBJECT: INFRARED ABSORPTION SPECTRA OF BROMOHYDROCARBONS
IN THE 15-35 MICRON REGION
INVESTIGATOR: Wilbert R. Powell
ABSTRACT: The infrared spectra of a series of aliphatic and aromatic bromides have been studied with the intent of establishing the carbon-bromine stretching vibration absorption band. Infrared spectra of the straight chain aliphatic series produce two strong absorption bands in the 15.5-15.7 micron and the 17.7 to 18.0 micron region due to the trans and gauche vibrations of the RCH₂-Br group. At least one strong absorption band, which appears to be

characteristic of a C-Br stretching vibration, is present in the 15-20 micron region in all the aliphatic bromides studied.

The assignment of bands to the carbon-bromine stretching vibration in aromatic bromides is complicated by the presence of bands due to vibrations of the aromatic ring structure.

WADC TR 57-468
ASTIA Document No. AD 155605

June 1958

SUBJECT: THERMAL PROPERTIES OF HIGH TEMPERATURE MATERIALS
INVESTIGATOR: Richard D. Seibel
George L. Mason
CONTRACT: AF 33(616)-3696
CONTRACTOR: Denver Research Institute
ABSTRACT: Equipment has been designed and built for the measurement of the specific heat, thermal conductivity and thermal expansion of a series of ten metals and ceramics. These measurements are from about 1000°F. to the melting point or 3000°F., whichever is lower. A vacuum dilatometer using a linear variable differential transformer as the sensing element has been used. A comparative method for measuring thermal conductivity has been used. The heat capacity was determined with an ice calorimeter and its associated high temperature furnace designed to operate up to 5000°F.

Data are presented for the expansion of all of the test materials. Enthalpy, specific heat and thermal conductivity data were determined for only part of the materials. All data are presented graphically.

WADC TR 57-627

November 1957

SUBJECT: PHOTO-CONDUCTIVE MATERIALS FOR USE IN HIGH
INTENSITY NUCLEAR RADIATION MEASUREMENTS
INVESTIGATOR: Robert J. Robinson
Leonid V. Azaroff
CONTRACT: AF 33(616)-3762
CONTRACTOR: Armour Research Foundation
ABSTRACT: This report describes the results of a one year program for the study of photoconductive materials for use in high intensity nuclear radiation measurements. The major accomplishment of this program is the correlation of gamma ray induced photoconductivity to the well known visible light induced photoconductivity. The phenomenological theory of photoconductivity is shown to apply to the gamma ray region as well as to the visible light region. The energy dependence observed in the response of CdS crystals is shown to be due to the energy dependence of the absorption process. The average ionization energy is shown to be in good agreement with independent

WADC TR 53-373 Sup 6

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measurements employing alpha and beta rays.

Two methods for growing single crystals, a flow system and a static system, were employed in the preparation of single crystals of cadmium sulfide. These can be grown large enough for device purposes, and with the desired electrical properties by control of the impurities added. Polycrystalline detectors can be prepared in several ways; however, their response properties are not as good as those obtained with single crystals.

WADC TN 58-46
ASTIA Document No. AD 155522
OTS Release

May 1958

SUBJECT: AN EXTRACTION PROCEDURE FOR THE DETERMINATION
OF THE METALLIC CONSTITUENTS IN GREASES
INVESTIGATOR: Larry A. Harrah, 1/lit.
ABSTRACT: A discussion is given of conditions required for the
extraction of the metallic ions from an organic liquid soap to an aqueous
phase previous to the determination of the metallic ion concentration.

An analytical procedure for these ions, using the flame
photometer, is proposed and evaluated.

WADC TN 58-56
ASTIA Document No. AD 155821
OTS Release

August 1958

SUBJECT: THE EVALUATION AND ADAPTATION OF THE BROMINATION
TECHNIQUE OF DETERMINING OXYGEN IN METALS
INVESTIGATOR: Lois A. Keyser
Charles D. Houston
ABSTRACT: This paper contains laboratory results and discussion
of the problem of determining oxygen in titanium and other metals using
the technique of bromination.

The gravimetric bromination equipment was adapted for
use with the conductometric carbon dioxide determinator so that the length
of time of bromination could be shortened and a lower range of oxygen could
be measured accurately.

An evaluation of the method and the recommendations for
its use is given.

May 1958

SUBJECT: A SIMPLIFIED AIR SAMPLING METHOD
INVESTIGATOR: Robert D. Thomas
ABSTRACT: This report describes a fast and efficient method of determining the radioactive particulate matter content of air. A comparison is made with the previous time consuming method to show the advantages of the new method. The method is unique for calibration since the counting system can be easily calibrated for any isotope to be used for comparison purposes. This method is definitely an advancement in the state-of-the-art for air sampling techniques.

WADC TR 58-59
ASTIA Document No. AD 155524

May 1958

SUBJECT: QUANTITATIVE DETERMINATION OF FLUORINATED
FUNGICIDAL AGENTS IN AIR FORCE MATERIEL
INVESTIGATOR: Harry V. Drushel
Doris J. Toft
CONTRACT: AF 33(616)-3998
CONTRACTOR: Mellon Institute
ABSTRACT: Methods for the extraction of the fungicides 1-fluoro-3-methyl-4,6-dinitrobenzene and 5,5'-difluoro-2,2'-dihydroxydiphenyl sulfide have been developed on the basis of the mechanism of interaction between the fungicide and the treated material. Numerous methods including polarography, spectrophotometry, and colorimetry have been shown to be useful for the determination of these fungicides. Leather, however, offers considerable difficulty during analysis because of serious interference from tannins which are simultaneously extracted. Steam distillation or azeotropic distillation with organic solvents was not successful for separating the fungicide from tannins. Anion exchange chromatography was used to separate the fungicide but this technique suffers from the disadvantage of being time-consuming. Some additional methods of separation and determination which have not, as yet, been examined are discussed. The choice of any one of the analytical methods described will depend upon the nature of the material which has been treated with the fungicide.

WADC TR 58-70
ASTIA Document No. AD 155630
OTS Release

June 1958

SUBJECT: HEAT CAPACITY DETERMINATION OF MINERAL AND SYNTHETIC
ENGINE OILS, LUBRICANTS, FUELS, AND HYDRAULIC FLUIDS
IN THE TEMPERATURE RANGE 70° - 500°F.

INVESTIGATOR: J. W. Barger T. M. Medved
C. C. Bolze
CONTRACT: AF 33(616)-5269
CONTRACTOR: Midwest Research Institute
ABSTRACT: An adiabatic calorimeter for measuring heat capacities of liquids in the temperature range 70° to 500°F was designed and constructed. Experimental technique and methods of calculation were devised to minimize errors. Using these calorimeters, the heat capacities of 32 mineral and synthetic engine oils, lubricants, fuels and hydraulic fluids were measured. The heat capacities were measured at five temperatures spanning the 70° to 500°F range. The calculated errors in the final results were 2 to 5 percent.

WADC TR 58-78
ASTIA Document No. AD 155871
OTS Release

September 1958

SUBJECT: THE EFFECTS OF GAMMA IRRADIATION ON ACRYLONITRILE-BUTADIENE COPOLYMERS
INVESTIGATOR: John A. Parker E. A. Peterson
Freeman F. Bentley Denver Hale
ABSTRACT: Changes in the chemical and physical properties produced by the irradiation of a series of acrylonitrile-butadiene copolymers varying in composition from 20 to 50% acrylonitrile with gamma photons from the cobalt-60 source at Wright Air Development Center have been measured and correlated with the nature of the copolymer, initial type of cure (sulfur, peroxide, or radiation), and the total integrated dose. This dose has been converted to the energy equivalent in graphite units now being recommended for standardized dosage terminology.

The efficiencies of these cross-linking processes induced by radiation have been estimated from the molecular weights between cross-links, M_c , determined by swelling volume measurements by a procedure similar to that used for natural rubber by Charlesby. This molecular weight varies with the radiation dose according to the general relationship:

$$M_c = \frac{m}{r^* + r_i}$$

Where r^* is the actual radiation dose incurred by the sample and r_i is an amount of radiation equivalent to the initial number of cross-links in the system. The slope varies with the particular copolymer.

The efficiencies of cross-linking determined in this way are a more realistic measure of the relative stabilities of these copolymers than

a comparison of the complex physical properties. Nevertheless, reasonable agreement exists between cross-linking densities determined by swelling volume and those determined by modulus measurements. The very regular behavior of the change in cross-linking density as a function of the total amount of energy deposited in terms of equivalent in graphite suggests the use of such polymers in dosimeter applications. These relationships enable one to predict the energy equivalent per gram of graphite for compositions cured by either sulfur or peroxides.

The qualitative changes in the chemical structure associated with the radiation induced cross-linking have been characterized by infrared spectra. By using the incremental change in modulus it is possible to apply the empirical equation proposed by Sisman and Bopp relating the change in Young's modulus to total dose. Specific constants for these equations have been calculated for this series of elastomers by means of which one may predict the useful life of mechanical rubber goods compounded from them in a radiation field of known intensity.

WADC TN 58-105
ASTIA Document No. AD 155571
OTS Release

May 1958

SUBJECT: BIBLIOGRAPHY ON PHOTOGRAPHIC FILM DOSIMETRY
INVESTIGATOR: Gordon H. Griffith, 2/Lt. USAF
ABSTRACT: This report contains a bibliography of several books and articles that have been published through 1957 on photographic film dosimetry. It has been divided into two parts, one for X- and gamma radiation and the other for neutrons. Brief abstract type comments are included with each reference.

WADC TR 58-112
ASTIA Document No. AD 155771
OTS Release

August 1958

SUBJECT: TRANSFORMATIONS OF SOLUTIONS OF DIFFUSION EQUATIONS
IN TWO-MEDIUM GEOMETRIES
INVESTIGATOR: Visvaldis Mangulis
CONTRACT: AF 33(616)-5187
CONTRACTOR: TRG, Incorporated
ABSTRACT: The purpose of the work performed was to find transformations of solutions of diffusion equations in certain two-medium situations for isotropic sources having simple geometric shapes. It is expected that the results will be applicable to some shielding problems. The transformations

were obtained for the following sources: point, disk, infinite plane, and solid cylinder sources interior to a semi-infinite medium joined at an infinite plane surface to a source free semi-infinite medium of a different material, and spherical shell or solid sphere sources interior to a spherical medium imbedded in an infinite medium of a different material.

WADC TR 58-129
ASTIA Document No. AD 155816
OTS Release

August 1958

SUBJECT: MEASUREMENT OF SOME THERMAL PROPERTIES OF THREE GLASSES
INVESTIGATOR: John V. Melonas
Perry C. Covington
Coultas D. Pears
CONTRACT: AF 33(616)-5264
CONTRACTOR: Southern Research Institute
ABSTRACT: The thermal conductivity and heat capacity were determined for the following three glass materials: (1) Soda-Lime Silica (Libbey-Owen-Ford 9330), (2) Borosilicate (Pittsburgh Plate Glass 3235), and (3) Alumina-Silicate Glass (Corning Glass Works 1723). This investigation covered the temperature range from -100°F to the strain point of the material.

WADC TN 58-134
ASTIA Document No. AD 155773
OTS Release

August 1958

SUBJECT: THE DETERMINATION OF NEAR INFRARED SPECTRA
INVESTIGATOR: Scott Anderson
Raymond Isaac
CONTRACT: AF 33(616)-5283
CONTRACTOR: The Anderson Physical Laboratory
ABSTRACT: Eight hundred and fifty (850) near infrared spectra of various classes of organic compounds and commercial mixtures, of interest to the Air Force Research and Development Program, were determined between the region 0.7 μ to 2.8 μ with the use of a Beckman DK-2 Ratio Recording Spectrophotometer.

Rapid sorting of spectra was provided with the use of Wyandotte - ASTM structure and name-formula IBM cards. A method for coding near infrared absorption bands on the standard Wyandotte - ASTM card was devised.

Methods of sample preparation and the use of solvents is discussed.

July 1958

SUBJECT: THE IDENTIFICATION OF CRYSTALLINE FERROCENES
BY X-RAY DIFFRACTION
INVESTIGATOR: William L. Baum, 1/Lt USAF
ABSTRACT: X-ray diffraction patterns for twenty-three solid crystalline ferrocenes are presented. These compounds are of interest because of their high thermal stability and wide potential applications. They are particularly well suited for x-ray diffraction analysis because of their crystalline nature and the individualistic patterns obtained from these compounds.

February 1959

SUBJECT: THE MECHANISM OF SOME SIMPLE CHEMICAL REACTIONS
OCCURRING UNDER THE ACTION OF IONIZING RADIATIONS
INVESTIGATOR: Lowell A. King, 1/Lt. USAF
ABSTRACT: A comparison of the suspected initial species formed in the radiation interaction primary act with the characteristics of subsequent chemical reactions affords the possibility to follow the roles of ionization, excitation, dissociation, and other initial processes in a radiation chemistry reaction and, in this way, explain its mechanism. Such comparisons are carried out in this report, and a summary of data is given pertaining to simple radiation chemistry reactions of hydrogen, oxygen, carbon, nitrogen, and a few of their most simple compounds.

July 1958

SUBJECT: INVESTIGATION OF EFFECTS OF RADIATION APPLICABLE AS
GAMMA RADIATION DOSIMETERS
INVESTIGATOR: J. F. Kircher B. W. King
M. J. Oestmann W. A. Hedden
J. H. Cahn J. Moody
P. Schall G. D. Calkins
CONTRACT: AF 33 (616)-3905
CONTRACTOR: Battelle Memorial Institute
ABSTRACT: This project was initiated to survey the field of radiation effects to determine which effects might be useful for high-level gamma dosimetry. Accordingly, the approach has been to survey the literature in broad areas and then to initiate experimental studies in those cases where additional information was required for evaluation of certain systems. It was not possible, however, to carry out experimental programs with all promising systems.

The areas investigated fall into four general categories: organic systems, inorganic oxidation-reduction reactions, semiconductor materials and devices, and ceramics.

Several promising organic systems are evaluated. Polymer systems and dye solutions will serve as dosimeters, but probably not to the high dosages desired. Reduction of metal oxides by hydrogen evolution from organic material holds promise but needs more study for proper evaluation.

The literature on radiation effects on inorganic reactions was surveyed but no experimental work was undertaken. However, some promising systems are pointed out.

A theoretical study of gamma-ray effects in semiconductor materials points up the energy dependence of this effect. It was demonstrated, however, that simple semiconductor devices can function as very high-intensity dose rate meters.

Several promising glass formulations were uncovered. These are primarily antimonate glasses, with and without added polyvalent metal oxides, and high-lead glasses. These glasses show promise of being useful dosimeters to the highest dosage of interest, 10^{12} ergs/g(C).

WADC TR 58-179
ASTIA Document No. AD 204795
OTS Release

November 1958

SUBJECT: MEASUREMENT OF THE THERMAL PROPERTIES OF VARIOUS
AIRCRAFT STRUCTURAL MATERIALS
INVESTIGATOR: John V. Melonas
Perry C. Covington
Coults D. Pears
CONTRACT: AF 33(616)-3328
CONTRACTOR: Southern Research Institute
ABSTRACT: Thermal expansion, specific heat, and thermal conductivity properties were measured for six structural panels and cores through a temperature range from -100 to 600°F. In addition, some physical tests were made on these materials. The materials covered in the investigation consisted of one asbestos-resin laminate, three fiberglass-resin laminates, and two fiberglass-resin fluted core sandwich panels.

The test procedures and equipment used in the thermal property evaluations are modifications of the procedure described in WADC TR 54-306 according to MIL and Federal specifications.

May 1958

SUBJECT: ANALYTICAL APPLICATIONS OF FAR INFRARED SPECTRA II.
SPECTRA-STRUCTURE CORRELATIONS FOR ALIPHATIC AND
AROMATIC HYDROCARBONS IN THE CESIUM BROMIDE REGION

INVESTIGATOR: Freeman F. Bentley
Eugene F. Wolfarth

ABSTRACT: The infrared absorption spectra of some 400 aliphatic and aromatic hydrocarbons have been investigated from 15 to 35 microns and the characteristic absorption frequencies incorporated into spectra-structure correlation charts. The classes of compounds studied were alkanes, alkenes, cyclopropanes, cyclobutanes, cyclopentanes, cyclohexanes, substituted benzenes, naphthalenes and biphenyls. The skeletal bending frequencies of the alkanes and alkenes and the nonplanar bending frequencies of cycloalkanes and aromatics are the most useful. The wavelength and intensity of the out-of-plane ring frequencies of aromatic molecules give some indication of the nature of the substituents. Typical infrared spectra of the hydrocarbons are presented.

WADC TR 58-198 Sup 1
ASTIA Document No. AD 207796
OTS Release

December 1958

SUBJECT: ANALYTICAL APPLICATIONS OF FAR INFRARED SPECTRA II.
SPECTRA-STRUCTURE CORRELATIONS FOR ALIPHATIC AND
AROMATIC HYDROCARBONS IN THE CESIUM BROMIDE REGION

INVESTIGATOR: Freeman F. Bentley
Eugene F. Wolfarth

ABSTRACT: The infrared absorption spectra of some 400 aliphatic and aromatic hydrocarbons have been investigated from 15 to 35 microns and the characteristic absorption frequencies incorporated into spectra-structure correlation charts. The classes of compounds studied were alkanes, alkenes, cyclopropanes, cyclopentanes, cyclohexanes, substituted benzenes, naphthalenes and biphenyls. The skeletal bending frequencies of the alkanes and alkenes and the non-planar bending frequencies of the aromatic hydrocarbons are the most useful for qualitative analysis in this region. The wavelength and intensity of the out-of-plane ring frequencies of aromatic molecules give some indication of the nature of the substituents. Typical infrared spectra of the hydrocarbons are presented.

WADC TR 58-206
ASTIA Document No. AD 202499
OTS Release

October 1958

SUBJECT: EFFECTS OF HIGH ENERGY, HIGH INTENSITY ELECTRO-
MAGNETIC RADIATION ON ORGANIC LIQUIDS

INVESTIGATOR: Robert M. Wagner
Leland H. Towle

CONTRACT: AF 33(616)-3738

CONTRACTOR: Stanford Research Institute

ABSTRACT: Materials employed for practical nuclear power applications must possess optimum resistance to radiation effects on their molecular structure. Although certain radiation effects are considered beneficial, the majority are degradative to an unacceptable degree at high dose levels. The functions of hydraulic and lubricating fluids in nuclear power auxiliary equipment are cases in point. These fluids must maintain viscosity and flash point at optimum levels. A knowledge of the effects of molecular structural characteristics upon radiolytic stability of organic materials is needed to aid in the efficient design of radiation-resistant equipment. Some materials may of necessity be located in a high flux density radiation field. This study attempts to provide, through the study of several representatives of different types of organic structure, background information which may suggest methods of judicious choice for a given application.

The following compounds were subjected to high energy electron bombardment: alkyl aromatic hydrocarbons, aromatic ethers, nitro aromatics, amino aromatics, and aliphatic mixed ether-alcohol types. Quantitative measurements were made of the amounts and types of radiolytic products formed. Inferences were drawn from such measurements concerning (1) the relative stability of compounds, and (2) the influence of functional groups upon such stability.

Higher molecular weight compounds in general, and condensed aromatic ring systems in particular, are the most resistant to radiation. Aliphatic or heterophatic linkages between aromatic ring systems are sites of primary radiolytic scission.

The extent to which species of higher molecular weight than parent material are formed is directly dependent upon the fate of the initial products of the scission of each radiolytically labile linkage. The primary products of scission may (1) hydrogenate and revert to stable form; (2) if energetic enough, they may attack parent material; or (3) they may condense with each other producing products comparable to the parent in molecular weight.

Compounds possessing the ability to assume certain spatial configurations, allowing resonance effects to exist, may permit absorbed energy to be innocuously reduced to levels which are below that required to rupture the molecular structure.

The presence of different functional groups on aromatic

ring systems markedly influence the mode of radiolytic scission. These differences are reflected in either gas yield, polymer yield, or both.

The data do not permit complete and unequivocal definition of either the mode of radiolytic decomposition or the delineation of the structure of all products detected.

Mechanisms for product formation are suggested in cases where the data are sufficiently coherent and complete to permit rational systemization.

WADC TR 58-274
ASTIA Document No. AD 206892
OTS Release

November 1958

SUBJECT: MEASUREMENTS OF THERMAL PROPERTIES
INVESTIGATOR: I. B. Fieldhouse

J. C. Hedge

J. I. Lang

CONTRACT: AF 33(616)-3701

CONTRACTOR: Armour Research Foundation

ABSTRACT: The objective of this program was the measurement of the high temperature thermal properties of materials. The materials investigated were Stainless Steel type 316, Stainless Steel type 347, Hastelloy R-235, Aluminum Oxide, Niobium, Lithium Hydride and Synthetic Sapphire. The thermal conductivity, specific heat, and linear thermal expansion were measured from 100°F to 3000°F, or to the melting point of the material, whichever was lower. All measurements were made in the Heat Transfer Laboratory of the Propulsion and Fluids Department, Armour Research Foundation of Illinois Institute of Technology. Both the experimental measurements and the results of the conversion of these measurements to the desired physical properties are given.

WADC TR 58-405
ASTIA Document No. 211693
OTS Release

March 1959

SUBJECT: THERMAL CONDUCTIVITY OF LUBRICATING OILS AND
HYDRAULIC FLUIDS

INVESTIGATOR: D. W. McCready

CONTRACT: AF 33(616)-3543

CONTRACTOR: University of Michigan

ABSTRACT: An all-metal concentric cylinder type of thermal conductivity cell was designed, fabricated, and calibrated to measure the thermal conductivity of forty natural and synthetic base lubricating fluids.

Thermal conductivity values in the temperature range of from 70 to 500°F are reported for fluids considered stable to the higher temperature. The maximum temperatures for other fluids were limited by their instabilities under test conditions. Since each fluid has individual characteristics, no correlation of conductivity values appears possible. Values are considered precise and for possible correlation can be compared to those of a fluid chosen as a "standard reference".

WADC TR 58-476
ASTIA Document No. AD 207905
OTS Release

January 1959

SUBJECT: THERMOPHYSICAL PROPERTIES OF SOLID MATERIALS
INVESTIGATOR: Alexander Goldsmith
Thomas E. Waterman
CONTRACT: AF 33(616)-5212
CONTRACTOR: Armour Research Foundation
ABSTRACT: Thermophysical property data for a number of solid materials are presented in both graphical and tabular form, with all entries annotated. Materials included are generally those with melting points in excess of 1000°F.

This volume is the partial result of the first year's effort in a program whose objective is the compilation, evaluation and consolidation of all primary test data published since 1940. Although this report is incomplete, it is representative of the end item. The reasons for its early distribution are to disseminate usable information on many important materials and to elicit comments and suggestions for improvement of the final product.

WADC TR 58-623
ASTIA Document No. AD 211914
OTS Release

March 1959

SUBJECT: A NEW INSTRUMENT FOR THE DETERMINATION OF MOLECULAR WEIGHT BY DIFFERENTIAL VAPOR PRESSURE
INVESTIGATOR: Norman M. Wiederhorn
Jay H. Vresland
Robert R. Perron
CONTRACT: AF 33(616)-5483
CONTRACTOR: Arthur D. Little, Inc.
ABSTRACT: A differential vapor pressure molecular weight instrument has been developed and constructed. The method developed is suitable for determining molecular weights of sparingly soluble (0.1% by weight) compounds in the 400 to 2000 molecular weight range to an accuracy of $\pm 5\%$. The measure-

ment involves a determination of the lowering of the vapor pressure by a known weight of material. For this purpose a differential pressure cell possessing the requisite sensitivity of 4 microns of mercury as well as necessary cells were constructed. This high sensitivity has been attained by using a metal foil as sensing element and determining its displacement by measuring the change in capacitance between the foil and a fixed test electrode. The necessary control of temperature gradients to $\pm 0.0001^\circ\text{C}$ was accomplished and preliminary calibration and investigation on sucrose solutions.

WADC TR 58-683
ASTIA Document No. AD 211915
OTS Release

March 1959

SUBJECT: EFFECTS OF HIGH ENERGY, HIGH INTENSITY ELECTROMAGNETIC RADIATION ON ORGANIC LIQUIDS
INVESTIGATOR: Robert M. Wagner
Leland H. Towle
CONTRACT: AF 33(616)-3738
CONTRACTOR: Stanford Research Institute
ABSTRACT: Practical nuclear power applications require organic materials which offer optimum resistance to the undesirable effects of radiation. Hydraulic and lubricating fluids in nuclear power auxiliary equipment are cases in point. Some of these may of necessity be located in a high flux density radiation field.

This study of several representatives of different types of organic structure was an attempt to provide background information which may suggest methods of judicious choice for the efficient design of radiation-resistant equipment.

The following compounds were subjected to high energy electron or gamma bombardment: aromatic amines, aromatic nitro compounds, alkyl aromatic ethers, alkyl aromatic hydrocarbons, and aliphatic esters. In addition, alkyl aromatic compounds and aliphatic esters were subjected to high energy neutron bombardment.

The data do not permit either complete and unequivocal definition of the mode of radiolytic decomposition, or complete delineation of the structures of all products detected. Conclusions were drawn concerning (1) the relative stability of compounds, and (2) the influence upon stability of the location and nature of functional groups. The conclusions derived from the thirty-month study are listed below.

1. Higher molecular weight compounds in general, and condensed aromatic ring systems in particular, are the most resistant to radiation.

Aliphatic or heterocyclic linkages between aromatic ring systems are sites of primary radiolytic scission.

2. The extent of formation of species of higher molecular weight than the parent material is directly dependent upon the fate of the initial products of the scission of each radiolytically labile linkage. The primary products may either (1) hydrogenate and revert to stable form, (2) attack parent material if energetic enough, or (3) condense with each other, producing products comparable to the parent in molecular weight.
3. Compounds not possessing the ability to assume certain spatial configurations, cannot utilize otherwise available resonance energy dissipation processes. Such processes would permit absorbed energy to be reduced to levels below that required to rupture the molecular structure.
4. The presence of different functional groups on aromatic ring systems markedly influences the mode of radiolytic scission. These differences are reflected in either gas yield, polymer yield, or both.
5. There is no linear relationship between the amount of methylene insulation between two aromatic systems and differences in radiolytic stability.
6. Unsymmetrical phenyl loading of a short alkyl chain does not alter the degree of radiolytic stability.
7. Alkyl unsaturation introduced between two aromatic systems facilitates hydrogen transfer to the target but does not reduce the total radiolytic instability of the system.
8. There is no essential difference in the yield or the nature of radiolytic products when alkyl aromatic hydrocarbons and aliphatic esters are irradiated with gamma rays, electrons, or neutrons.
9. An oxygen-rich atmosphere did not effectively scavenge energy, and thus inhibit radiolysis damage during electron bombardment of either alkyl aromatic hydrocarbons or aliphatic esters.
10. Branching of aliphatic chains induces radiolytic instability in either esters or hydrocarbons.

WADC TN 59-79
ASTIA Document No. AD 214763
OTS Release

May 1959

SUBJECT: INVESTIGATION OF A NEW DYE-GLASS GAMMA RADIATION DOSIMETER

INVESTIGATOR: Denver Hale

ABSTRACT: This report was an investigation of the effects of gamma radiation on a unique organic dye - porous glass system. Effect of gamma ray dosage on the optical absorbancy of Methylene Blue, Fluorescein, Rhodamine B, Fast Reds S, and Brilliant Green dyes absorbed in Corning "thirsty glass" are presented. Data appear to be analytical and to follow Beer's law, thereby allowing one to relate optical absorbancy with radiation dosage.

These experiments were of an exploratory nature, and although not complete, do indicate that this absorption of dyes in a porous glass matrix merits additional study for possible use as dosimeters in the range of 10^9 or higher erg gm^{-1} carbon gamma dosage.

WADC TR 59-119

April 1959

ASTIA Document No. AD 211918
OTS Release

SUBJECT: REMOVAL DOSE AS AN ENVIRONMENTAL MEASUREMENT OF
X-RAY AND GAMMA RAYS

INVESTIGATOR: R. L. Hickmott

ABSTRACT: The Removal Dose of any material is the net energy per unit mass that a limitingly small mass of the material transfers from the incident photon flux to the kinetic energy of the associated flux of charged particles. Removal Dose is compared to both Absorbed Dose and Exposure Dose (roentgen) in terms of cross sections and spectra. Its relation to radiation effects is compared to the similar relation of Absorbed Dose.

METALLURGICAL PHENOMENA AND MECHANISMS

WADC TN 58-369

May 1959

ASTIA Document No. 212151
OTS Release

SUBJECT: OBSERVATIONS ON THE EFFECT OF SURFACE AND STRUCTURE
ON THE TENSILE STRENGTH OF IRON WHISKERS

INVESTIGATOR: Helmut Weik

ABSTRACT: Investigations were made of iron whiskers grown by reduction of iron chloride. Characteristic whisker shapes were found to be dependent on the growth conditions. Observations of the surface of the whiskers after the test revealed normal slipping on slip planes connected

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with low tensile strength in the case where the whiskers were grown from wet chloride. In the case where they were grown by reduction of dried chloride in hydrogen and argon, however, much higher values for the tensile strength were obtained. The strength increases with decreasing whisker diameter. On the surface of some whiskers from this series shearing of surface layers could be observed giving the impression that the whisker surface has a layer or shell structure. By means of microstructure investigations the layers observed in the surface were also discovered in the whisker core. The distance between the layers was found to be constant and about 1200 to 1500 atoms thick. It may be concluded that the layers are a structural element of the whiskers grown under the conditions above mentioned.

Nickel coating of the whiskers increased the tensile strength. In the case of a 100 atoms thick nickel coating the amount of increase was about 100% compared to the strength value of the uncoated whisker. That means that surface effects are important in considering the reasons for the extremely high tensile strength of very thin whiskers.

WADC TR 58-507
ASTIA Document No. AD 211850
OTS Release

March 1959

SUBJECT: THE EFFECT OF STRESS ON THE CREEP BEHAVIOR OF
HIGH PURITY ALUMINUM IN THE REGION OF DISLOCATION
CLIMB

INVESTIGATOR: A. Bayce
W. Ludemann
L. A. Shepard
J. E. Dorn

CONTRACT: AF 33(616)-3860

CONTRACTOR: University of California

ABSTRACT: The effect of stress on the creep rate in the dislocation climb region was investigated by increasing and decreasing the stress abruptly during the course of primary creep of high purity aluminum. These investigations revealed that a simple functional relationship between creep rate and stress does not exist; the effect of stress on the creep rate depended on the substructure as well as the stress. In general the creep of aluminum under conditions of changes in stress can be resolved qualitatively in terms of dislocation climb models for creep.

WADC TR 58-547
ASTIA Document No. AD 206667
OTS Release

December 1958

SUBJECT: DAMPING ENERGY DISSIPATED BY INTERFACES IN BEAM
AND PLATE SUPPORTS AND IN SANDWICH CORES
INVESTIGATOR: Theodore J. Mentel
CONTRACT: AF 33(616)-5426
CONTRACTOR: University of Minnesota
ABSTRACT: The maximum energy dissipation which can result from both viscous and dry friction damping between the longitudinal interfaces at the supports of built-in beams and plates is compared with the total material damping. This comparison shows that this type of support damping is relatively unimportant in the vibration attenuation problem for beams, but may be extremely important in the case of thin plates. An alternative method for the damping of beams, that of using sandwich construction with an energy dissipating central core, is found to provide an effective damping mechanism in the cases where support damping becomes ineffective.

WADC TR 58-569
ASTIA Document No. AD 214382
OTS Release

May 1959

SUBJECT: RESPONSE OF BARS(WITH INTERNAL AND BOUNDARY DAMPING)
TO TRANSIENT AND RANDOM EXCITATION
INVESTIGATOR: Robert F. Lambert
CONTRACT: AF 33(616)-5426
CONTRACTOR: University of Minnesota
ABSTRACT: Theoretical analysis of the effects of internal and boundary damping on the forced vibrations of a uniform bar is carried out using perturbation techniques. A first order correction to the poles of the response function is obtained and the dependence upon frequency noted. It turns out that the real part (damping factor) will in general vary with frequency and hence mode number. In the case of internal damping it varies as approximately n^2 where n is the mode number. In the case of a low boundary damping parameter, the damping constant varies as n^2 while for high boundary damping it has roughly an n^4 dependence. These results virtually insure that the response functions (displacement, moment, strain) for random excitation obtained using a generalized Fourier analysis will converge for Brownian motion type excitation. Relationships showing the mode shape corrections for finite boundary impedances are obtained from the perturbation theory. Several experimental studies are suggested which would contribute to our understanding of these damping mechanisms and their relative importance in studies involving random excitation of bars and plates.

METALS, GENERAL

October 1958

SUBJECT: THE EFFECTS OF INELASTIC ACTION ON THE RESISTANCE
TO VARIOUS TYPES OF LOADS OF DUCTILE MEMBERS MADE
FROM VARIOUS CLASSES OF METALS
Part VIII - Eccentrically-Loaded Tension Members
Made of Two Stainless Steels Tested at Elevated
Temperatures

INVESTIGATOR: O. M. Sidebottom
M. E. Clark
S. Dharmarajan

CONTRACT: AF 33(616)-2753

CONTRACTOR: University of Illinois

ABSTRACT: This report presents the results of an analytical and
experimental investigation for the determination of the load necessary to
produce a specified amount of inelastic deformation in rectangular-section
members subjected to eccentric tensile loads at elevated temperatures.
Two different theories were used. In one theory each isochronous stress-
strain diagram was represented by two straight lines, and the load and de-
flection of the eccentrically loaded members were obtained from interaction
curves and moment-load curves. In the other theory each isochronous stress-
strain diagram was represented by a hyperbolic sine curve, and the resultant
theory is called the hyperbolic sine theory.

In the experimental investigation, tests were made on
eccentrically-loaded rectangular-section members made of type 304 stain-
less steel at a test temperature of 1000°F and 17-7 PH stainless steel at
test temperatures of 1000°F and 1200°F. Some of the 17-7PH stainless
steel specimens were given a precipitation hardening treatment and some
were tested in the untreated condition.

The type 304 stainless steel did not creep at 1000°F.
The interaction curve--moment-load curve theory was found to give satis-
factory results. The heat treated 17-7PH stainless steel was found to
have higher strength than the untreated, and it was found to exhibit a
small amount of inelastic deformation for zero time but a larger amount of
creep in 30 min. when tested at 1000°F. The untreated 17-7PH was found to
creep a small amount at 1000°F and a much greater amount at 1200°F. In
each case the isochronous stress-strain diagram could be represented by a
hyperbolic sine curve. It was found that the load and/or deflection for
the eccentrically loaded members could be adequately represented by either
the hyperbolic sine theory or the interaction curve--moment-load theory.
The former gave the best results.

October 1958

SUBJECT: THE EFFECTS OF INELASTIC ACTION ON THE RESISTANCE TO
VARIOUS TYPES OF LOADS OF DUCTILE MEMBERS MADE FROM
VARIOUS CLASSES OF METALS
Part IX - T-Section Eccentrically-Loaded Tension Members
Made of Type 304 Stainless Steel and Tested at 1000°F.

INVESTIGATOR: O. M. Sidebottom
S. Dharmarajan

CONTRACT: AF 33(616)-2753

CONTRACTOR: University of Illinois

ABSTRACT: This report presents the results of an analytical and experimental investigation for the determination of the load necessary to produce a specified amount of inelastic deformation in T-section members subjected to eccentric tensile loads at 1000°F. The interaction curve-moment-load curve theory was used in predicting the load and deformation of the eccentrically-loaded members.

The material used in making the test members was type 304 stainless steel. Creep tension tests indicated that this material was extremely time-insensitive, at least, for the first 30 minutes. The stress-strain diagram of the material at 1000° F was similar in shape to that at room temperature.

The comparison between the theory and experiment for the T-section eccentrically-loaded members was excellent for those members with sufficiently small initial eccentricity that yielding did not occur in the most stressed compression fibers. For those members with larger eccentricity, the experimental moment-load curves fell appreciably below the theoretical curve over the range of the curve for which yielding had occurred on the compression side of the member. It is believed that this discrepancy results from the fact that the yield stress in compression was less than in tension.

January 1959

SUBJECT: NOTCH SENSITIVITY OF AIRCRAFT STRUCTURAL AND ENGINE
ALLOYS
Part II - Further Studies with A-286 Alloy

INVESTIGATOR: Howard R. Voorhees
James W. Freeman

CONTRACT: AF 33(616)-3380

CONTRACTOR: University of Michigan

ABSTRACT: Sufficient data on a single lot of A-286 alloy were obtained at 1200°F to permit future evaluation of an analysis for notched-bar rupture life in terms of normal creep-rupture properties.

Circumferential notches with theoretical stress concentration factors (K_t) of 3.0 or less increased rupture time of materials with a 2200°F solution temperature, despite smooth-bar elongations as low as 0.5% or below.

Notch behavior varied widely with notch geometry in tests on specimens with 1800°F solution temperature. Transition to notch sensitivity at longer time periods was, however, positively demonstrated for several notch geometries.

The creep rate of a smooth bar at any time in a variable-stress test appeared to be a unique function of the existing stress level and the cumulative portion of rupture life already expended. No exact criterion was found for rupture of A-286 alloy after creep under variable simple tension; for engineering purposes the portion of rupture life consumed in a time interval (Δt) during which creep deformation (ΔC) occurred could be evaluated by

$$\sqrt{\frac{(\Delta t)(\Delta C)}{(R)(D)}}, \text{ where } R \text{ and } D \text{ are the rupture time and creep}$$

deformation at rupture in a normal test at the existing stress.

Firm criteria for creep rupture under a general state of variable complex stress are still lacking for the desired evaluation and extension of the proposed calculation methods.

WADC TR 58-168
ASTIA Document No. AD 202497
OTS Release

October 1958

SUBJECT: STRESS RELAXATION IN STRUCTURAL MATERIALS

INVESTIGATOR: Alfred M. Freudenthal

CONTRACT: AF 33(616)-2729

ABSTRACT: The phenomenon of stress-relaxation is discussed in relation to its physical origin, its mathematical representation, its experimental determination and its design significance, with particular emphasis on the interrelation between creep and relaxation in metals and in polymers.

While the relaxation behavior of materials is of primary importance in design, particularly with regard to flight structures operating under conditions of varying temperatures, it appears that neither the present methods of direct "relaxation testing" nor the conversion of creep-data into

relaxation-data provide useful and reliable information concerning the relaxation behavior of the material.

WADC TR 58-615 Pt I
ASTIA Document No. AD 210719
OTS Release

March 1959

SUBJECT: A COMPENDIUM OF CONSTITUTIONAL TERNARY DIAGRAMS
OF THE METALLIC SYSTEMS
INVESTIGATOR: Dr. W. Guertler, Berlin, Germany
CONTRACT: AF 61(052)-74
ABSTRACT: The purpose of this project is to collect and present a complete collection of ternary phase diagrams of the various metallic systems.

The ternary diagrams presented are built from available binary diagrams. In each instance the most reliable binary diagram has been selected.

The basis for the designation of the pages is the order of atomic numbers. It is thus possible to attribute to each ternary alloy three numbers below 100 corresponding to the three combining elements and to assemble them in order of magnitude from the smallest to the highest figure. Consequently each system can be located easily.

METALS, HIGH TEMPERATURE

WADC TR 54-270 Pt 3
ASTIA Document No. AD 151194
OTS Release

May 1958

SUBJECT: INVESTIGATION OF THE COMPRESSIVE, BEARING AND SHEAR
CREEP-RUPTURE PROPERTIES OF AIRCRAFT STRUCTURAL
METALS AND JOINTS AT ELEVATED TEMPERATURES
INVESTIGATOR: Luke A. Yerkovich
CONTRACT: AF 33(616)-190
CONTRACTOR: Cornell Aeronautical Laboratory, Inc.
ABSTRACT: The establishment of high-temperature creep and rupture properties of materials is a prerequisite for efficient design if exposure to elevated temperature in service is expected. These properties, which

are generally determined from the conventional creep test, are not necessarily applicable if stress conditions other than tension are encountered. This project was initiated to supplement the usual tensile creep and rupture data. The high-temperature creep strengths of a number of structural aircraft alloys were determined when under the influence of compression, bearing, and shear stresses. Specifically, data of these types are required to formulate high temperature joint design criteria.

This report summarizes three years study on the creep behavior of fifteen sheet, plate, and bar alloys creep tested in tension, compression, bearing, and shear. In addition, correlations of tensile creep and rupture properties with compression, bearing and shear creep-rupture properties have been made and are presented in tabular form.

WADC TR 54-270 Pt IV
ASTIA Document No. AD 155570
OTS Release

May 1958

SUBJECT: INVESTIGATION OF THE COMPRESSIVE, BEARING AND
SHEAR CREEP-RUPTURE PROPERTIES OF AIRCRAFT
STRUCTURAL METALS AND JOINTS AT ELEVATED TEMPERATURES

INVESTIGATOR: Luke A. Yerkovich

CONTRACT: AF 33(616)-3456

CONTRACTOR: Cornell Aeronautical Laboratory, Inc.

ABSTRACT: The establishment of the high-temperature mechanical properties of aircraft constructional materials is a prerequisite to efficient design when elevated temperature service is expected. These properties, which normally are determined from the conventional short-time tensile test and the tensile-creep test, are not necessarily applicable if stress conditions other than tension are encountered. The present program was initiated to examine the high-temperature strength characteristics of a number of aircraft structural alloys when subjected to a variety of stresses under both short and long time loading with the specific purpose of applying these high-temperature characteristics to riveted joint configurations.

This report summarizes in tabular form the high-temperature short-time strength properties of a number of test alloys in tension, compression, bearing, and shear. Data representing the bearing creep behavior of 2024-T3 aluminum alloy sheet for a number of variables associated with bearing are also included. The creep behavior of several selected joint designs undergoing bearing and shear creep are illustrated as time-deformation charts, and comparisons between the predicted and experimental performances are made.

December 1958

SUBJECT: INVESTIGATION OF THE COMPRESSIVE, BEARING, AND SHEAR CREEP-RUPTURE PROPERTIES OF AIRCRAFT STRUCTURAL METAL AND JOINTS AT ELEVATED TEMPERATURES

INVESTIGATOR: Luke A. Yerkovich

CONTRACT: AF 33(616)-3456

CONTRACTOR: Cornell Aeronautical Laboratory, Inc.

ABSTRACT: The establishment of the high-temperature mechanical properties of aircraft structural materials is a prerequisite to efficient design when elevated temperature service is expected. Normally these properties are determined from the conventional short-time tensile and creep-rupture tests and as such are not necessarily applicable for stress conditions other than tension. The present program was conducted to examine the high temperature strength and deformation characteristics of two high-strength airframe alloys when subjected to a variety of stresses under both short and long time loading. Specifically the object of the program was to determine the high-temperature tension, compression, bearing and shear properties of selected airframe alloys with the ultimate purpose of correlating tension behavior with behavior under the various other types of loads and applying these basic data to predict the behavior of riveted joints undergoing creep deformation in tension, bearing, and shear.

This report summarizes in tabular and chart form the high temperature properties of PH15-7 Mo stainless steel and 6Al-4V titanium alloy in tension, compression, bearing, and shear. In addition correlations of the tensile creep-rupture properties with corresponding compression, bearing, and shear creep-rupture properties are presented.

The creep-rupture characteristics of doubler type riveted joints, which represent single units of a multiple riveted assembly, prepared from the test alloys are presented herein. Correlations between measured joint creep-rupture and predicted joint creep-rupture are also included.

October 1958

SUBJECT: INVESTIGATION OF Fe-Mn-Cr-N-C SYSTEM FOR HEAT RESISTANCE AND OXIDATION RESISTANCE BETWEEN 1200F AND 2000F

INVESTIGATOR: J. P. Tarwater
E. J. Dulis
CONTRACT: AF 33(616)-3318
CONTRACTOR: Crucible Steel Company of America
ABSTRACT: Austenitic Cr-Mn-C-N steels containing various combinations of V, Nb, W, and/or Mo had, after heat-treating, room- and elevated-temperature tensile properties and creep-rupture strengths that compared favorably with those of such superalloys as A286 and Inco 901.

Proper selection of composition and heat-treatment enabled development of adequate ductility in tension and creep rupture although a marked decrease in impact properties could not be avoided.

Calcium additions improved the creep rupture strength of Cr-Mn-C-N steels that did not contain additions of strengthening elements (V, Nb, Mo, and W). A silicon addition of about 2% to high-chromium Cr-Mn-C-N steels increased the oxidation resistance at 2000 and 2200°F so that these steels compared favorably with Type 310 stainless steel.

Both strengthened and unstrengthened austenitic Cr-Mn-C-N steels could be hot-rolled to sheets without the formation of edge cracks or surface defects, but rolling pressures higher than those for Type 310 stainless steel were required.

WADC TR 57-298 Pt 4
ASTIA Document No. AD 151102

April 1958

SUBJECT: IRON-ALUMINUM ALLOY SYSTEMS
PART 4 - The Activities of Aluminum and Iron in Iron-Aluminum Melts at 1600°C
INVESTIGATOR: R. D. Pehlke
CONTRACT: AF 33(600)-32448
CONTRACTOR: Ford Motor Company
ABSTRACT: The activities of the components in molten iron-aluminum alloys at 1600°C. have been calculated by utilizing the phase diagram. Consideration was made of the equilibria along the liquidus boundary of the intermetallic compound Fe_2Al_5 and known distribution data for aluminum in iron to determine the activity of aluminum in iron-aluminum melts at 1600°C. The activity of iron was then found by graphically integrating the Gibbs-Duhem relationship.

WADC TR 57-298 Pt 5
ASTIA Document No. AD 151103

April 1958

SUBJECT: IRON-ALUMINUM ALLOY SYSTEMS
PART 5 - Some Investigations in Air-Melting and Application of Iron-Aluminum Alloys

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INVESTIGATOR: William J. Zager
CONTRACT: AF 33(600)-32448
CONTRACTOR: Ford Motor Company
ABSTRACT: During the period April 1957 to September 1957, the Process Development Department of the Manufacturing Engineering Office of Ford Motor Company air-melted a series of heats of iron-aluminum alloys in the 6 to 10% aluminum range. The melting and deoxidation of these heats, performed in induction furnaces are described. Mechanical properties obtained on bar stock rolled from ingots cast from several of these heats, as well as properties of the as-cast alloys are listed.

Further attempts to produce sound castings in sand molds are described.

Performance of iron-aluminum alloy fabricated articles in service is described.

WADC TR 57-298 Pt 6
ASTIA Document No. AD 151104

April 1958

SUBJECT: IRON-ALUMINUM ALLOY SYSTEMS
PART 6 - Welding of Iron-Aluminum Alloys
INVESTIGATOR: R. Burthwick
S. Goodman
CONTRACT: AF 33(600)-32448
CONTRACTOR: Ford Motor Company
ABSTRACT: Supplementing a previous report, WADC Technical Report 57-298 Part 3 (AD-130825), additional mechanical test data was established for the effect of fusion welding on three different analyses of iron-aluminum alloy. The consumable electrode gas shielded arc process was briefly investigated. Additional fabrications were selected for evaluation of iron-aluminum material and work initiated.

WADC TR 57-298 Pt 7
ASTIA Document No. AD 151105

April 1958

SUBJECT: IRON -ALUMINUM ALLOY SYSTEMS
PART 7 - Study of Magnetic Properties
INVESTIGATOR: H. Sato
A. Arrott
CONTRACT: AF 33(600)-32448
CONTRACTOR: Ford Motor Company
ABSTRACT: From a study of magnetic isotherms over the range of compositions from pure Fe to 40 atomic percent Al in Fe and over temperatures from 4°K to 300°K we have produced strong evidence for the existence of super-exchange interactions between iron atoms separated by aluminum atoms. The

iron rich alloys show ferromagnetism in the usual way, but for concentrations approaching 40 atomic percent Al the alloys behave as typical antiferromagnetics with Neel points near liquid hydrogen temperatures. There is a transition range of composition in which the stable state just below the Curie temperature is ferromagnetic but at low temperatures is antiferromagnetic.

The large changes in magnetic properties occur for the ordered structures and in composition ranges where the number of nearest neighbor iron-iron interactions is changing rapidly with composition, but where the number of next nearest neighbor iron-iron interactions remain practically constant. These considerations lead to a model where only nearest neighbor direct positive exchange interactions between iron atoms and indirect negative exchange interactions between iron atoms separated by an aluminum atom are taken into account. The treatment by a Bragg-Williams type calculation leads to a qualitative understanding of the observed magnetic effects in the aluminum system including the differences between the disordered state and the two types of ordered states. The model also leads to a reinterpretation of neutron diffraction data.

WADC TR 57-298 Pt 8
ASTIA Document No. AD 155659

June 1958

SUBJECT: IRON-ALUMINUM ALLOY SYSTEMS
PART 8 - Mechanical Properties of Fe-Al-Si
Alloys at Room and Elevated Temperatures

INVESTIGATOR: D. J. Schmatz
V. F. Zackay

CONTRACT: AF 33(600)-32448

CONTRACTOR: Ford Motor Company

ABSTRACT: An investigation of the mechanical properties of iron-rich, iron-aluminum-silicon alloys was conducted. Silicon was used as the independent variable at three aluminum levels; 5, 7 and 9 weight percent. Silicon increased the strength at both room and elevated temperatures. Ductility was markedly decreased by silicon and interstitial elements, such as carbon. Silicon appeared to be more than additive to aluminum in improving the oxidation resistance. Room temperature electrical resistivity measurements on quenched and slow cooled alloys indicated silicon was additive to aluminum in initiating order. Silicon also raised the ordering temperature rapidly. A correlation between ordering temperature, as determined by electrical resistivity and creep rate was noted.

WADC TR 57-298 Pt 9
ASTIA Document No. AD 155660

June 1958

SUBJECT: IRON-ALUMINUM ALLOY SYSTEMS
PART 9 - SOME INVESTIGATIONS IN AIR-MELTING AND
APPLICATION OF IRON-ALUMINUM ALLOY
INVESTIGATOR: William J. Zager
CONTRACT: AF 33(600)-32448
CONTRACTOR: Ford Motor Company
ABSTRACT: During the period October 1, 1957 through March 31, 1958, the Process Development Department of the Manufacturing Engineering Office of Ford Motor Company air-melted several heats of iron-aluminum alloys in the 6 to 10% aluminum range. The melting and deoxidation of these heats, performed in induction furnaces are described. Mechanical properties obtained on cast tensile bars are listed.

Effect of cold deformation (compression) tests on one of the wrought alloys is described.

Performance of iron-aluminum alloy fabricated articles in service is described.

WADC TR 57-298 Pt 10
ASTIA Document No. AD 155661

June 1958

SUBJECT: IRON-ALUMINUM ALLOY SYSTEMS
PART 10-WELDING OF IRON-ALUMINUM ALLOYS
INVESTIGATOR: R. Brooks
A. Volio
CONTRACT: AF 33(600)-32448
CONTRACTOR: Ford Motor Company
ABSTRACT: The work conducted during this reporting period is a continuation of the investigations to develop both fusion and resistance welding processes for iron-aluminum alloy fabrication as reported under Document No. 151104. The limited work conducted using the tungsten arc gas shielded process further verified the need for pre and postweld heat treatment. An investigation was initiated to develop coated manual arc welding electrodes for welding iron-aluminum alloys. With aluminum added to the coating, it was possible to obtain a weld metal deposit with up to 10% aluminum content. Resistance spot and stitch welding schedules were developed for the material thicknesses to be used in fabricating the J-57 engine turbine exhaust cone. Two different approaches in making the cone body blank were tried to eliminate cracking during hot spinning of the cone detail without success. A two part blank welded together after spinning to form the complete cone body is now in process. A large carburizing box was fabricated and put in service. Severe cracking was experienced during welding and in service.

WADC TR 57-298 Pt 11
ASTIA Document No. AD 207907

November 1958

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SUBJECT: IRON-ALUMINUM ALLOY SYSTEMS
PART 11 - Comparative Study of Oxidation Resistance
in the Fe-Al System
INVESTIGATOR: Richard E. Heimerdinger
CONTRACT: AF 33(600)-32448
CONTRACTOR: Ford Motor Company
ABSTRACT: A Study of the oxidation resistance of Fe-Al alloys with
varying aluminum content has been made. Visual observations confirm the
effect of aluminum (0 - 16 percent) on the oxidation resistance of Fe-Al
alloys at temperatures to 2200°F and for periods of up to 500 hours.

Attempts to quantitatively determine weight gain of Fe-Al alloys were not successful. The lack of reproducible weight gain data is suggested to be a result of oxide seams and inclusions.

The addition of chromium was found to be beneficial only at the 7.50 percent chromium level. The apparent deleterious effects of chromium at levels both higher and lower than 7.50 percent is to be further investigated. An alloy containing 7.50 percent aluminum and 7.50 percent chromium is recommended for further study in view of its good oxidation resistance, corrosion resistance, and ductility.

WADC TR 57-298 Pt 12
ASTIA Document No. AD 207908

November 1958

SUBJECT: IRON-ALUMINUM ALLOY SYSTEMS
PART 12 - Welding of Iron-Aluminum Alloys
INVESTIGATOR: R. Brooks
A. Volio
CONTRACT: AF 33(600)-32448
CONTRACTOR: Ford Motor Company
ABSTRACT: During the period from March 31, 1958, through September 30, 1958, further investigations were conducted for both fusion welding and resistance welding procedures for iron-aluminum alloys. Additional resistance spot and stitch welds were developed for heats E-1005 and E-1006. Fabrication of a J-57 Turbine Exhaust Cone made from iron-aluminum alloys was completed and submitted for testing. The forming and fusion welding processes used for this cone were described in WADC Technical Report 57-298, Part 10. Information on the resistance welding of the stiffener and flange to the cone body are contained herein.

Investigations were continued toward the development of coated iron-aluminum electrodes for manual arc welding to provide a weld metal deposit containing 7-9% aluminum content.

A program for investigating High Temperature Brazing was

initiated for two reasons, (1) to develop a high strength brazing joint in iron-aluminum alloys suitable for use at elevated temperatures, and (2) to investigate brazing problems which would be likely in connection with aircraft fabrications.

WADC TR 57-298 Pt 13
ASTIA Document No. AD 213472

May 1959

SUBJECT: IRON-ALUMINUM ALLOY SYSTEMS
PART 13 - Development of Creep Resisting Compositions
INVESTIGATOR: Roger H. Richman
CONTRACT: AF 33(600)-32448
CONTRACTOR: Ford Motor Company
ABSTRACT: Utilization of oxidation-resistant iron--7-percent aluminum as a basis for creep-resisting high temperature materials was the objective of the research described in this report. Data are presented to illustrate the effects of 1 to 4 percent molybdenum and 1/2 to 1 percent titanium upon the mechanical and metallurgical properties of iron--7 aluminum. All the compositions except those containing a nominal 0.25-percent silicon demonstrated good room temperature mechanical properties, after oil-quenching or air cooling from the recrystallization anneal, but only alloys of 3 and 4 percent molybdenum and 1/2 to 1 percent titanium possessed promising elevated temperature properties. From correlation of age-hardening studies with stress-rupture test results it was concluded that molybdenum and titanium served primarily as solid solution strengtheners. Suggestions for the modification of the composition to improve the high temperature performance are presented.

WADC TR 57-298 Pt 14
ASTIA Document No. AD 213473

May 1959

SUBJECT: IRON-ALUMINUM ALLOY SYSTEMS
PART 14 - Welding of Iron-Aluminum Alloys
INVESTIGATOR: R. Brooks
A. Volio
CONTRACT: AF 33(600)-32448
CONTRACTOR: Ford Motor Company
ABSTRACT: During the period from October 1, 1958 to January 31, 1959, investigations were continued to develop fusion welding procedures for iron-aluminum alloys. Fabrication of a furnace hearth and heat-treatment box made from iron-aluminum alloys was completed and they were submitted for service. The manufacturing and fusion welding processes used for these applications are described herein.

A J-57 Turbine Exhaust Cone of iron-aluminum alloy that

was submitted for testing was returned to the Welding Development Department. This cone was damaged during endurance testing. Metallographic examination and mechanical testing were conducted on material from the damaged cone.

WADC TR 57-343 Pt II
ASTIA Document No. AD 203524
OTS Release

October 1958

SUBJECT: A STUDY OF THE METALLURGICAL PROPERTIES THAT ARE NECESSARY FOR SATISFACTORY BEARING PERFORMANCE AND THE DEVELOPMENT OF IMPROVED BEARING ALLOYS FOR SERVICE UP TO 1000°F

INVESTIGATOR: T. V. Philip
A. E. Nehrenberg
G. Steven

CONTRACT: AF 33(616)-3318

CONTRACTOR: Crucible Steel Company of America

ABSTRACT: To develop a bearing steel for operating temperatures up to 1000°F, fifty-one experimental compositions were studied. This report describes the theoretical considerations which formed the basis of the formulation of these steels as well as the annealing cycle, austenitizing temperature survey, and the tempering survey. The results of the tempering studies are plotted as "master tempering curves".

From the study of the temper resistance, eight steels were selected for further evaluation tests. These tests consisted of (1) hot hardness determinations, (2) dimensional stability measurements, (3) compression tests at room temperature and elevated temperature, (4) oxidation resistance, and (5) hot oil corrosion resistance.

As a result of the foregoing tests, a steel of the following composition is recommended for use as a bearing steel for operating temperatures up to 1000°F:

| C | Cr | V | W | Mo | Co |
|------|-----|-----|-----|-----|-----|
| 1.09 | 4.2 | 1.9 | 6.7 | 3.7 | 5.2 |

The steel should be heat-treated as follows: austenitize at 2225°F, oil quench, and temper for two consecutive 2-hour periods at 1050°F.

This work has not only developed a steel for elevated-temperature bearing applications but it has also clarified the effects of alloying elements on secondary hardness, hardness retention at elevated temperatures, and other properties desired of a high-temperature bearing steel.

May 1958

SUBJECT: DEVELOPMENT OF NIOBIUM-BASE ALLOYS
INVESTIGATOR: Richard T. Begley
CONTRACT: AF 33(616)-3316
CONTRACTOR: Westinghouse Electric Corporation
ABSTRACT: The flow and fracture characteristics of commercial purity powder metallurgy niobium were investigated in the range 250 to -196°C. Niobium was found to undergo a ductile-brittle transition in the range -125 to -196°C, and the transition temperature range of niobium was found to be less affected by the presence of interstitial impurities than many other body-centered cubic metals.

The creep-rupture properties of powder metallurgy niobium were investigated at 982 and 1093 C (1800 and 2000 F), and the 100-hour rupture strength of commercial niobium in vacuum was determined to be significantly greater than unalloyed molybdenum. The creep-rupture results suggest that small quantities of gaseous contaminants may be responsible for the high strength of commercial niobium at elevated temperatures.

The oxidation behavior of niobium was investigated in the temperature range 350 to 700 C. At the higher temperatures, oxidation followed a linear rate law. Between 500 and 625 C, the rate of oxidation was found to be nearly independent of temperature.

Oxygen and nitrogen contamination of welding atmospheres was studied to determine its effect on the weld properties of niobium. Nitrogen was established to be very detrimental to the mechanical properties of niobium welds.

High-purity niobium, having a hardness of less than 60 VPN, was produced by cage-zone refining techniques.

March 1959

SUBJECT: DEVELOPMENT OF NIOBIUM-BASE ALLOYS
INVESTIGATOR: Richard T. Begley
CONTRACT: AF 33(616)-3316
CONTRACTOR: Westinghouse Electric Corporation
ABSTRACT: Flow and fracture studies indicate that the ductile to brittle transition of niobium is little affected by oxygen content in the range 0.01 to 0.1% O₂. The impact transition range of electron-beam melted niobium was found to be considerably below that of powder metallurgy niobium of somewhat higher oxygen concentration.

Strain-hardening and strain aging in niobium were studied. An activation energy of 27,100 cal/mol was determined for strain aging in niobium. The recrystallization behavior of electron-beam melted niobium was studied in detail.

Creep-rupture data were obtained on electron-beam melted niobium at (871 C) 1600 F and (982 C) 1800 F. The electron-beam material had much lower rupture strength than powder metallurgy niobium containing 0.6% Zr tested previously. The effect of temperature on the modulus of elasticity of niobium and tantalum was determined in the range 25 C to 900 C.

Studies of the thermodynamics of niobium oxides and the kinetics of Nb-water vapor reaction were carried out. The thermodynamic functions obtained in this study for the formation of Nb_2O_5 from Nb_2O_4 are in excellent agreement with calculated values.

A selection of the most promising weldable niobium-base alloys was made on the basis of available physical and mechanical property data.

Niobium of low oxygen and nitrogen content was produced by cage-zone and floating zone melting techniques. Evaluation of material prepared by electron-beam melting and vacuum arc melting was carried out.

WADC TR 58-164 Part I
ASTIA Document No. AD 155688
OTS Release

June 1958

SUBJECT: OXIDATION OF EXPERIMENTAL ALLOYS
INVESTIGATOR: Joseph C. Richmond
H. Richard Thornton
CONTRACT: AF 33(616)-56-19
CONTRACTOR: National Bureau of Standards
ABSTRACT: A study was made of the oxidation resistance of ten high-temperature alloys; 1) aluminum-modified Nichrome V, 2) Nichrome V, 3) niobium-modified Nichrome V, 4) an iron-chromium-aluminum alloy, 5) Inconel 702, 6) Hastelloy R235, 7) Hastelloy W, 8) type 316 stainless steel, 9) Inconel X and 10) Inconel. Tests included the measurement of the average depth of external oxidation and maximum depth of oxide penetration on specimens that had been subjected to stress in air at high temperature for 100 hours, and on specimens that had been subjected to stress in air under fluctuating-temperature conditions for an equivalent length of time, plus continuous recording of the weight change of specimens oxidized in air at high temperatures.

The depth of oxidation was found to increase with temperature and with stress. There was little effect of stress at stresses below that required to produce 1% extension in 100 hours. All of the alloys conformed reasonably well to the parabolic rate law in the weight-gain oxidation tests.

WADC TR 58-164 Part II
ASTIA Document No. AD 209379
OTS Release

February 1959

SUBJECT: OXIDATION OF EXPERIMENTAL ALLOYS
INVESTIGATOR: Joseph C. Richmond
H. Richard Thornton
CONTRACT: AF 33(616) 56-19
CONTRACTOR: National Bureau of Standards
ABSTRACT: A study was made of the oxidation resistance of five newly-developed high-temperature alloys: two nickel-molybdenum-chromium alloys and three iron-chromium-aluminum alloys. Tests included the measurement of the average depth of external oxidation and maximum depth of oxide penetration on specimens that had been subjected to stress in air at high temperature for 100 hours, and on specimens that had been subjected to stress in air under fluctuating-temperature conditions for an equivalent length of time. The weight change of specimens oxidized in air at high temperatures was continuously recorded for periods up to 100 hours.

The depth of oxide penetration was found to increase with temperature and with stress. There was little effect of stress at stresses below that required to produce one percent extension in 100 hours. All of the alloys conformed reasonably well to the parabolic rate law in the weight-gain oxidation tests.

WADC TR 58-181
ASTIA Document No. AD 155689
OTS Release

June 1958

SUBJECT: A RESEARCH PROGRAM ON THE INVESTIGATION OF SEAL
MATERIALS FOR HIGH TEMPERATURE APPLICATION

INVESTIGATOR: Raymond H. Baskey
CONTRACT: AF 33(616)-3891
CONTRACTOR: Horizons Incorporated
ABSTRACT: Novel rotating seal materials for potential aircraft applications at high speed and high temperatures were developed and tested under conditions of no external lubrication. These materials were arrived at after a systematic study of the wear behavior of:

1. Pure refractory hard metals
2. Binary alloys of pure refractory hard metals, bonded with nickel
3. Ternary alloys of pure refractory hard metals, bonded with nickel and infiltrated with silver.

Tests were conducted to determine the benefit derived from additions of nickel or silver to the refractory hard metals. The nickel acts as a tough, oxidation-resistant matrix. The silver was added to act as a lubricant as it softens at high temperatures. This aids the shearing action between mating surfaces and lowers the surface friction.

Two ternary alloys prepared by powder metallurgy techniques and consisting of high percentages by weight of a refractory hard metal, with nickel and silver additions, show superior wear qualities when run against either tool steel or Inconel. Tests were made at sliding speeds of 30,000 fpm and ambient temperatures up to 1350°F. The best alloys contained either tungsten boride (WB) or chromium nitride (CrN) as the hard refractory metal.

The WB alloy exhibited a constant wear rate at all temperatures against tool steel. The wear rate of the CrN alloy decreased at the higher temperatures.

All ternary alloys run against Inconel displayed a decrease in wear rate at ambient temperatures over 600°F. The wear decreased as a function of temperature for several ternary alloys against tool steel.

An unimpregnated graphite seal coated with an oxidation resistant layer of zirconium carbide showed improved wear properties over a regular graphite impregnated seal at an ambient temperature of 1050°F and sliding speeds of 14,000 fpm against stainless steel type 303.

The finest wear performance was attained when Kentanium K162B ran against Kentanium K162B at sliding speeds of 14,000 fpm in an ambient temperature of 1100°F.

It is hypothesized that the wear process is drastically influenced by the oxidation occurring on the rubbing surfaces and that with proper choice of materials, stable, complex oxides are formed which provide the correct solid lubricating film on each component and markedly lower the wear rate as the temperature is increased.

WADC TR 58-299
ASTIA Document No. AD 203787
OTS Release

October 1958

SUBJECT: A STUDY OF REFRACTORY MATERIALS FOR SEAL AND
BEARING APPLICATIONS IN AIRCRAFT ACCESSORY
UNITS AND ROCKET MOTORS

INVESTIGATOR: L. B. Sibley C. L. Peterson
C. M. Allen W. H. Goldthwaite
W. J. Zielenbach

CONTRACT: AF 33(616)-3995

CONTRACTOR: Battelle Memorial Institute

ABSTRACT: A number of ceramic, cermet, and high-temperature alloy materials have been evaluated for corrosion resistance and for friction and wear behavior in an oxidizing atmosphere from 1000 to 1800 F. Rubbing-wear experiments were conducted at 200 feet per second sliding speed with about 20-psi load pressure usually applied to the contact surfaces. Several material combinations involving an alumina-chromium-molybdenum cermet, silicon carbide, alumina, and perhaps a titanium carbide-nickel-molybdenum cermet may be satisfactory for short-life rubbing-seal applications under these conditions. The applications of these materials are limited since they wear rapidly and exhibit erratic frictional behavior. Superficial surface cracking was observed on the wear surfaces of all specimens containing brittle ceramic phases except possibly silicon carbide. A wear-failure mechanism for refractory materials under sliding contact is postulated, and some correlation of the experimental results with conventional thermal-stress-resistance parameters is obtained.

Two rubbing-wear experiments were conducted in a high-temperature reducing atmosphere. The static corrosion resistance of several potential bearing and seal materials was determined in a nitric acid oxidizer used in some rocket-propellant pumps. Experimental ceramic and cermet materials were fabricated, and some of these specimens were evaluated in rubbing-wear experiments in the oxidizing atmosphere to study certain material-property effects on friction and wear behavior.

WADC TR 58-396
ASTIA Document No. AD 203901
OTS Release

November 1958

SUBJECT: DEVELOPMENT OF PROCEDURES AND TECHNIQUES FOR PREPARING
BONDED DOUBLE LAYER TANTALUM-COPPER COMPOSITE PLATES

WADC TR 53-373 Sup 6

99

INVESTIGATOR: R. C. Bertossa
S. Rau
CONTRACT: AF 33(616)-5215
CONTRACTOR: Stanford Research Institute
ABSTRACT: The purpose of this project was to develop a process for bonding tantalum sheet to OFHC copper. This was successfully accomplished both by casting molten copper directly into an annealed tantalum cone under controlled vacuum-inert gas atmospheres, and by using intermediate brazing alloys to produce high integrity, vacuum bonded joints between OFHC copper and annealed tantalum.

Metallurgical and microhardness evaluations reveal that sound, continuous bonds can be effected, with ductile interfaces, in joining OFHC copper to annealed tantalum by vacuum-inert gas techniques.

Physical tests on brazed copper-tantalum composite plates show excellent bond strengths under multi-axial stresses encountered in 180° flat bends and in cold forming of flat composite plate into nose-cone shapes.

Elevated temperature tests on copper-tantalum clad nose-cones, both uncoated and metal or ceramic coated on the exposed tantalum surfaces, exhibited the ability of selected brazing alloys to maintain intimate contact between the copper and tantalum at temperatures up to the melting point of copper. The high thermal conductivity of the copper layer enabled it to absorb sufficient heat from the tantalum surface to allow the tantalum cone shell to contain the molten copper as long as two minutes at temperatures above 2000°C (measured optically on the exposed tantalum).

WADC TR 58-432
ASTIA Document No. AD 208148
OTS Release

January 1959

SUBJECT: AN INVESTIGATION OF THE MECHANICAL PROPERTIES OF CERMETS
AS RELATED TO THE MICROSTRUCTURE
INVESTIGATOR: Ira Binder
Robert Steinitz
CONTRACT: AF 33(616)-5084
CONTRACTOR: Firth Sterling, Inc.
ABSTRACT: A summary of cermet literature, especially that pertaining to microstructure, was made. Using 60 TiC - 40 Ni as the test material, seven different test groups were formulated, comprising changes in original particle size, processing procedure, and controlled binder addition. Each test group was heated in seven different fashions.

Each test batch so obtained was tested for physical properties and its microstructure was investigated. The microstructures were correlated with changes in physical properties.

WADC TR 58-525
ASTIA Document No. AD 206073
OTS Release

November 1958

SUBJECT: INVESTIGATION OF THE PROPERTIES OF TANTALUM AND ITS ALLOYS
INVESTIGATOR: William D. Klopp Chester T. Sims
Fred R. Schwartzberg H. Russell Ogden
Frank C. Holden Robert I. Jaffee
CONTRACT: AF 33(616)-5668
CONTRACTOR: Battelle Memorial Institute
ABSTRACT: A survey of literature pertaining to tantalum and tantalum alloys has been carried as part of the study of the properties of tantalum and its alloys. The results of that survey are reported in narrative style with references to published data. A bibliography of available publications is included. Emphasis was placed on subjects pertinent to the research being conducted on this project with a more general coverage of other subjects.

WADC TR 58-546
ASTIA Document No. AD 206666
OTS Release

December 1958

SUBJECT: EVALUATION OF ALLOYS FOR HIGH TEMPERATURE GEAR APPLICATIONS
INVESTIGATOR: E. G. Jackson E. H. Rowe
C. F. Muench E. H. Scott
CONTRACT: AF 33(616)-5266
CONTRACTOR: General Electric Company
ABSTRACT: The selection of materials for use in high mach number aircraft gears requires consideration of high temperature physical, mechanical and chemical properties, and of rubbing compatibility. This program was designed to obtain bench test data on ten different materials for application as gears at operating temperatures to 700°F. Oils representing two important classes, silicone and mineral, were chosen for scoring tests.

High temperature data were obtained on hardness, dimensional stability, tensile, impact and tooth fatigue strengths, corrosion and oxidation, and on surface scoring resistance.

The most fatigue resistant material was Modified M50, Carburized, while Matrix M2 was the best of the through-hardened steels. In score resistance, the best material depended on the oil; L.P.D. (Vacuum), Nitrided was the best with silicone, but M1 rose from second place with silicone to first with mineral oil. Choice of material for any application must depend on whether tooth breakage or scoring is the limiting factor, however, the L.P.D. (Vacuum) Nitrided is the best compromise since it ranked high in all tests.

March 1959

SUBJECT: DEVELOPMENT OF TESTING PROCEDURES AND EVALUATION OF
REFRACTORY MATERIALS

INVESTIGATOR: John M. Allen
James L. Harp

CONTRACT: AF 33(616)-5301

CONTRACTOR: Battelle Memorial Institute

ABSTRACT: In this work specimens of several materials, both with and without protective coatings, were subjected to severe heat pulses to determine their capacity as a heat sink. Results were compared on the basis of the amount of heat a specimen could absorb without experiencing surface failure by melting or chemical reaction. The heat pulses were imposed by placing the materials in the throat of an H_2-O_2 rocket motor and operating the motor in such a manner that the heat flux increased to a maximum in 12 seconds and decreased during the next 12 seconds. By suitable calibration, the instantaneous applied heat flux and the integrated heat impulse were determined. It was found that 1-inch-thick copper can absorb an integrated heat impulse of 12,000 Btu/(ft²) in a 24-second period when the maximum heat flux at the midpoint of the pulse is 822 Btu/(ft²)(sec). Similarly, nickel can absorb 7500 Btu/(ft²) with a maximum flux of 570 Btu/(ft²)(sec). Graphite protected by a coating of silicon carbide formed in place can absorb approximately 9000 Btu/(ft²) in a strongly oxidizing atmosphere with a peak heat flux of 600 Btu/(ft²)(sec) before the protective coating is destroyed. More severe exposure caused drastic failure of the surface of each of these materials.

WADC TR 59-10, Part I
ASTIA Document No. AD 214427

May 1959

SUBJECT: DEVELOPMENT AND EVALUATION OF MATERIALS FOR HIGH
TEMPERATURE APPLICATIONS

INVESTIGATOR: Charles E. Shulze Gustave E. Mangsen
Frank A. Saulino James C. Andersen
William T. Adams Howard W. Emmons

CONTRACT: AF 33(616)-5542

CONTRACTOR: The Carborundum Company

ABSTRACT: Various preparational techniques have been used to fabricate graphite-based bodies which have potential resistance to high velocity, high temperature air. Materials have been evaluated in a high intensity arc testing facility. Results are reported herein.

At least ten compositions have been developed which are superior to either AGKSP graphite or to a graphite-silicon carbide body on the bases of tests imposed.

METALS. FERROUS

WADC TR 57-720 Part I
ASTIA Document No. AD 206076

November 1958

SUBJECT: THE EFFECT OF PRESTRAIN AND RETEMPERING ON ULTRA-HIGH STRENGTH STEEL
INVESTIGATOR: Edward T. Stephenson Benjamin L. Averbach
Morris Cohen
CONTRACT: AF 33(616)-2012
CONTRACTOR: Massachusetts Institute of Technology
ABSTRACT: The mechanical properties of pretempered, prestrained, and retempered ultra-high strength steel are reported here. Pretempering temperatures were varied from 400 to 1200°F, prestrains from 0 to 7% elongation, and retempering temperatures from 70 to 1200°F.

It is found that prestrain and retempering may cause a significant increase in the yield stress and tensile strength, but with an accompanying loss of ductility and toughness. On increasing the retempering temperature, a maximum occurs in the strength along with a minimum in the ductility and toughness. The temperature of the maximum shifts from 300 to 700°F with increasing pretempering temperature, and the minimum behaves similarly.

Any tempering-prestrain combination which increases the strength appreciably also decreases the elongation-to-maximum-load to practically zero. This behavior severely limits the possible application of prestrained ultra-high strength steel.

Prestrain and retempering (below the pretempering temperature) have no observable effect on the fracture stress, the hardness, or the electron microstructure.

Several phenomena are considered in an attempt to account for the results of this investigation. Substructure seemed to be the most promising model for explaining the observed behavior. However, the evidence is inconclusive.

WADC TR 59-57
ASTIA Document No. AD 214426

May 1959

SUBJECT: THE EFFECT OF SILICON ON THE TEMPERING OF HIGH STRENGTH STEELS
INVESTIGATOR: C. J. Altstetter B. L. Averbach
Morris Cohen

WADC TR 53-373 Sup 6

103

CONTRACT: AF 33(616)-5161
CONTRACTOR: Massachusetts Institute of Technology
ABSTRACT: The tempering of steels with a base composition of AISI 43XX and up to 3% silicon was studied by measuring longitudinal mechanical properties and kinetic behavior. The kinetic analysis was performed on precision-length measurements after isothermal tempering treatments from 72° to 850°F; mechanical properties were evaluated after one hour tempers at temperatures up to 1300°F.

It was found that silicon affects the temperature at which the first-stage decomposition products transform to cementite and ferrite, although silicon has no marked influence on the first stage itself. In steels without added silicon, the transformation of low-carbon martensite and epsilon carbide to ferrite and cementite (which is the third stage in iron-carbon alloys) is split into two substages because of the stabilizing effect of the alloying elements on epsilon carbide. The first substage is the transformation of low-carbon martensite to thin-plate cementite and ferrite, and the second is the resolution of epsilon carbide and the precipitation of cementite. In silicon steels, the last two reactions occur simultaneously because of the higher transformation temperatures.

The changes in the matrix and carbide phases are reflected in the mechanical properties. A decrease in matrix carbon content causes a decrease in hardness and ultimate strength. Likewise, an agglomeration of carbide also causes a decrease in these properties. The influence of silicon on the as-quenched hardness is considered to be due, at least in part, to its effect on quench-tempering. The "500°F embrittlement phenomenon" is attributed to the morphology of the first-formed cementite. Silicon permits tempering to higher temperature by inhibiting both the softening effect of carbon depletion from the matrix as well as the embrittling effect of cementite precipitation.

METALS, NONFERROUS ALUMINUM

WADC TN 58-57
ASTIA Document No. AD 155672
OTS Release

June 1958

SUBJECT: METALLURGICAL INVESTIGATION OF ALUMINUM ALLOY X2219-T6
INVESTIGATOR: Paul L. Hendricks
ABSTRACT: This investigation was undertaken to determine some design properties of aluminum alloy X2219-T6 at room and elevated temperatures. The investigation including the determination of tensile properties,

fatigue properties, stress rupture properties and stress corrosion characteristics of aluminum alloy X2219-T6 under various temperature conditions up to 600°F.

METALS, NONFERROUS MAGNESIUM

WADC TR 58-218
ASTIA Document No. AD 204797
OTS Release

November 1958

SUBJECT: FORGING CHARACTERISTICS AND PROPERTIES OF HM21XA AND EK31XA MAGNESIUM ALLOY PRODUCTION FORGINGS
INVESTIGATOR: J. F. Pashak
CONTRACT: AF 33(616)-3578
CONTRACTOR: The Dow Chemical Company
ABSTRACT: This production closed-die forging program was established for the purpose of determining the forging characteristics and properties of two high temperature magnesium alloys, HM21XA and EK31XA, in five sets of commercial design tools. Both cast and extruded material were used as forging stock. Test specimens for room and elevated temperature testing were taken from the forgings in normal production test locations after the HM21XA forgings were aged to the -T5 temper and the EK31XA forgings were heat treated to the -T6 condition.

EK31XA alloy is readily forgeable in regular hydraulic presses and the Air Force heavy presses with stock temperatures of 750-950F and die temperatures of 700-850F. HM21XA alloy is relatively stiff to forge in this temperature range and the alloy is also susceptible to cracking when subjected to bending moments during the forging cycle. The cast forms of both alloys are slightly stiffer to forge than the extruded forms.

The strength properties and creep resistance of EK31XA-T6 production forgings are outstanding at temperatures to 500F. Properties of HM21XA-T5 forgings, although lower than anticipated at moderate temperatures, duplicate those obtained on laboratory material at the higher testing temperatures. Optimum properties are obtained in this alloy by strain hardening and maintaining the Mn content at about 0.60%. Modulus, shear, bearing, and fatigue properties for both alloys are presented at appropriate testing temperatures.

METALS, NONFERROUS TITANIUM

WADC TR 54-616 Part V
ASTIA Document No. AD 209378
OTS Release

February 1959

SUBJECT: HYDROGEN CONTAMINATION IN TITANIUM AND TITANIUM ALLOYS
PART V. HYDROGEN EMBRITTLEMENT
INVESTIGATOR: D. N. Williams R. I. Jaffee
F. R. Schwartzberg
CONTRACT: AF 33(616)-5007
CONTRACTOR: Battelle Memorial Institute
ABSTRACT: Extensive investigations intended to provide information relating to the mechanism of hydrogen embrittlement in titanium-base alloys were carried out. Studies included detailed measurements of the effects of temperature, strain rate, and hydrogen content on hydrogen embrittlement; examination of all-alpha and all-beta alloys for susceptibility to hydrogen embrittlement; calculations of probable hydrogen solubility in alpha and beta titanium; and several other informative investigations. An embrittlement mechanism is outlined. Alloys previously prepared and examined to determine the effects of alloy content and microstructure on hydrogen embrittlement (WADC TR 54-616, Part IV) were further studied by means of notched stress-rupture tests. This work has resulted in some alteration in previously expressed conclusions regarding alloying and microstructural effects.

WADC TR 58-105
ASTIA Document No. AD 155850
OTS Release

August 1958

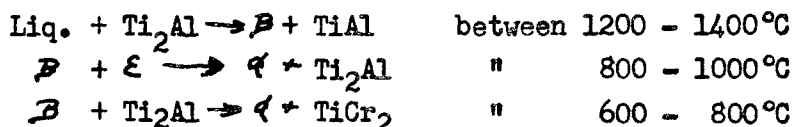
SUBJECT: REINVESTIGATION OF THE SYSTEMS Ti-Al-Cr AND Ti-Al-V
CONTRACT: AF 33(616)-3619
CONTRACTOR: New York University
ABSTRACT: The Ti-Cr and Ti-V systems have been investigated in the range of 2-36% Cr and 2-36% V in the temperature range 500°-1150°C (Cr) and 500°-900°C (V), with both iodide titanium and Bureau of Mines titanium as base material. Conventional and rapid-quenching techniques were employed.

In the Ti-Cr system, the $\beta/\alpha+\beta$ boundary was lower than that generally obtained by conventional quenching. The β transus exhibited a change in slope at about 750°C for both iodide titanium and Bureau of Mines titanium. The $\beta/\beta+TiCr$ boundary seemed to be shifted towards lower chromium content when the Bureau of Mines titanium was used as base. The eutectoid temperature was found to be between 660° and 670°C for iodide titanium base alloys.

In the Ti-V system, the β/α boundary was in agreement with most of the earlier determinations. Below 650°C it was found to be greatly obscured by the presence of an impurity phase.

Ti-Al-Cr System:

Five tentative isothermal sections of the titanium-rich corner (up to 40% Al and 32% Cr) of the Ti-Al-Cr system have been constructed at 200-degree intervals between 600 and 1400°C. The following ternary reactions appear to take place:



A miscibility gap in the β field is produced by the interaction of the $\beta + \text{Ti}_2\text{Al}$ and the $\beta + \text{TiCr}_2$ fields. The ϵ -phase has been encountered microscopically and this phase is believed to be a binary Ti-Al phase occurring in the binary Ti-Al system in the vicinity of 12% Al below approximately 1100°C.

Ti-Al-V System:

The titanium-rich corner of the Ti-Al-V system has been investigated in the region up to 45 wt% Al and up to 35 wt% V and between 700 and 1400°C. Eight isothermal sections at 100-degree intervals are presented.

The phases encountered in this region were those which have been identified as being present or probably present in the binary Ti-Al system, namely α , β , ϵ , Ti_2Al and TiAl .

WADC TR 58-161
ASTIA Document No. AD 155835
OTS Release

August 1958

SUBJECT: A STUDY OF BETA EMBRITTLEMENT IN HIGH-STRENGTH
TITANIUM ALLOYS
INVESTIGATOR: Andrew J. Griest Herbert A. Robinson
Arthur P. Young Paul D. Frost
CONTRACT: AF 33(616)-5007
CONTRACTOR: Battelle Memorial Institute
ABSTRACT: Studies were conducted to determine the importance of beta grain size as a contributing factor to the loss of ductility that occurs when titanium alloys are heat treated at temperatures above the beta transus. In a second phase of the research a heat-treatment program

was carried out in an effort to develop procedures for restoring ductility in beta-embrittled material. To supplement these studies, a microscopic study of deformation in pertinent microstructures was conducted.

As a result of these investigations, it was concluded that:

- (a) The primary cause of beta embrittlement is the large **grain size** which is obtained so rapidly in many alpha-beta titanium alloys when heated into the beta field. Grain-boundary alpha and acicular intragranular alpha in the microstructure are not detrimental if the beta grain size is fine.
- (b) The structures resulting from beta treatments are quite stable and can not be significantly altered in a beneficial way by heat treatment alone.
- (c) Certain alloys (such as Ti- 16V- 2.5Al) show a relatively low rate of beta grain growth. Development of alloys exhibiting this property appears to offer the most promising means of avoiding or minimizing beta-embrittlement effects.

WADC TR 58-182
ASTIA Document No. AD 155796
OTS Release

August 1958

SUBJECT: DEVELOPMENT OF A HEAT TREATABLE TITANIUM SHEET ALLOY
INVESTIGATOR: C. Robert Lillie
David W. Levinson
CONTRACT: AF 33(616)-3320
CONTRACTOR: Armour Research Foundation
ABSTRACT: The objective of this research program was to develop heat treatable titanium sheet alloys capable of providing 160,000 psi yield strength, 0.2% offset, at room temperature. The material should be easily rolled to light gages, of the order of 0.020 in., possess excellent formability in the solution-treated condition, and be stable under stress, as heat treated, for at least 500 hours at 600° and 800°F. Good weldability was secondary in desirability to the foregoing requirements.

The program was divided into two parts, designated as Phase I and Phase II. Phase I had as its purpose the screening of fifteen alloys in order to select the four most promising for more intensive investigation in Phase II. Of the fifteen alloys, four were of the alpha-beta type, utilizing the strengthening effect of a precipitation-hardener, beryllium; seven alloys were alpha-beta type, based on well-known successful combinations of aluminum with the beta-formers, manganese, molybdenum, and

vanadium, and dependent for strengthening on the substitution of the alpha-formers, tin or zirconium, for part of the aluminum; the remaining three alloys were of the metastable-beta type, containing 2.5% aluminum for alpha strengthening, and sufficient amounts of manganese, molybdenum, or vanadium to produce a mechanically unstable beta phase after suitable heat treatment.

The optimum heat treatments for each of these alloys were determined by bend test screening to establish the best solution-treating temperatures, followed by an aging program to fix the temperatures and times of aging which yielded promising hardness values. These combinations of solution treatment and aging were then checked out by tensile testing.

The four alloys selected for work under Phase II were:

Ti-3Al-7Mo-0.25Be
Ti-3Al-2Sn-4Mn
Ti-2Al-2Sn-7Mo
Ti-2.5Al-7Mn

In Phase II of the program these four alloys were evaluated by bend testing and tensile testing, by measurement of uniform elongation in the solution treated condition, and by stress stability testing for 500 hours at 800° and 600°F.

Two alloys, Ti-3Al-7Mo-0.25Be and Ti-2.5Al-7Mn, reasonably fulfilled the objectives of the program with regard to bend properties and tensile properties, and were stable under a stress of 25,000 psi for 500 hours at 800°F; however, neither alloy is weldable.

WADC TR 58-328
ASTIA Document No. AD 202501
OTS Release

October 1958

SUBJECT: DEVELOPMENT OF ACTIVE-EUTECTOID BASE ALLOYS
INVESTIGATOR: R. F. Bunshah
H. Margolin
CONTRACT: AF 33(616)-3942
CONTRACTOR: New York University
ABSTRACT: Titanium-copper alloys form an active eutectoid titanium alloy system in which the decomposition of the beta phase to alpha plus compound occurs rapidly. This alloy development program is a study of the effect of stepwise additions of Al and/or Sn and/or Zr to binary Ti-2Cu, Ti-4Cu, and Ti-6Cu alloys. The alloys were forged as far as possible in the $\alpha+\beta$ field and annealed at 750°C for 24 hours to alpha plus compound. The

alloys were evaluated by tensile tests at room and elevated temperatures. Limited stress-rupture and stability tests were also carried out. Several alloys showed excellent tensile properties particularly in the range 1000 to 1200°F. A Ti-6Cu-7Al-6Zr alloy was outstanding, showing a tensile strength of 108,900 psi at 1200°F. These alloys show promise of utility in the 1000 to 1200°F range. Instability apparently associated with the Ti-Al phases was encountered.

WADC TR 58-409

January 1959

ASTIA Document No. AD 207791

OTS Release

SUBJECT: HEAT TREATMENT RESPONSE, MECHANICAL PROPERTIES AND STABILITY OF TITANIUM SHEET ALLOYS

INVESTIGATOR: Eugene Delgrosso Brian Weldon
Peter Kuzmenko A. Richard Zello
Allan Springmeyer James Chafey

CONTRACT: AF 33(616)-3585

CONTRACTOR: Chase Brass and Copper Co., Incorporated

ABSTRACT: The effect of various heat treatments on the mechanical properties of two titanium alloys was determined. The two types of heat treatments utilized were: (1) solution treatment and water quench, (2) solution treatment, water quench and age. The alloys, Ti-4Al-3Mo-1V and Ti-15V-2.5Al, were investigated in the form of approximately 0.040" sheet. Three interstitial content levels of each alloy were investigated.

Beta transus temperatures were determined for the alloys. Room temperature mechanical properties were evaluated for the solution treated and aged conditions of the alloys for both standard and notched tensile configurations. Elevated temperature tensile properties were determined. The effect of deformation, via two degrees of rolling or stretching, on aging characteristics was ascertained. Three hundred hour creep tests were conducted at 600°F and 800°F. Creep embrittlement was evaluated. A microstructural examination was conducted. Also, the alloy Ti-4Al-1Pb-1Sn-1V-1Zr was prepared in sheet form and some of its mechanical properties were evaluated.

WADC TR 58-438

December 1958

ASTIA Document No. AD 207078

OTS Release

SUBJECT: AN INVESTIGATION OF THE EFFECTS OF IMPURITIES AND METALLURGICAL VARIABLES ON THE NOTCH SENSITIVITY OF TITANIUM ALLOYS

WADC TR 53-373 Sup 6

110

INVESTIGATOR: Frank C. Holden Horace R. Ogden
Richard W. Douglass Robert I. Jaffee
CONTRACT: AF 33(616)-5007
CONTRACTOR: Battelle Memorial Institute
ABSTRACT: The notch tensile properties of three commercial titanium-base alloys, ALLOAT (Ti-5, OAl-2.5Sn), Ti-6Al-4V, and Ti-140A (Ti-2Fe-2Cr-2Mo), were investigated at six interstitial levels, four microstructural conditions, and over a range of temperatures from -196 to 200 C. Notch sensitivity generally was increased by increased interstitial content, low temperature, and acicular-type microstructures. In addition, sensitivity to slow-strain hydrogen embrittlement was observed in the temperature range near 0 C at hydrogen levels well below specification limits.

PACKAGING

WADC TR 57-541
ASTIA Document No. AD 205550

November 1958

SUBJECT: DEVELOPMENT OF PLASTIC FOAMING EQUIPMENT
INVESTIGATOR: George W. Pearce
Sidney Allinikov
CONTRACT: AF 33(600)-32235
CONTRACTOR: United Engineers, Incorporated
ABSTRACT: The design, development, fabrication and evaluation of an operable foaming equipment system for producing mechanically foamed plastic materials is described. Engineering research into the selection of plastic materials suitable for use with the equipment is discussed. Polyethylene was selected as the initial material to be mechanically foamed. A 12 lb. per cu. ft. density foam was achieved with polyethylene. This proved to be the lowest density foam produced with the equipment at present state of development. Polyvinyl chloride, styrene, and nylon were foamed in densities of 18, 15, and 17 lbs. per cu. ft. respectively.

Densities of all the foams produced were higher than the 1.5 to 6 lbs. per cu. ft. target range considered acceptable for cushioning purposes. However, it was successfully demonstrated that plastic materials can be foamed by mechanical means.

November 1958

SUBJECT: THE CUSHION FACTOR-STRESS CURVE AND ITS VALUE FOR
CLASSIFYING AND SELECTING PACKAGE CUSHIONING MATERIALS

INVESTIGATOR: R. K. Stern

CONTRACT: PO (33-600)53-4023

CONTRACTOR: Forest Products Laboratory

ABSTRACT: "Cushion factor-stress" curves have been considered for use in solving package cushioning problems and for classifying package cushioning materials. To be most suitable for these uses, a single essentially constant curve would express the compressive efficiency of any specific material regardless of its dimensions or loading rate. The dynamic compression test data derived from this work showed that the curve for at least one important material varies considerably with thickness, and the use of this type of curve is considered to be impractical. The report contains data for the compressive efficiency and variability of four common kinds of package cushioning materials differing in thickness, density, and manufacturing origin.

February 1959

SUBJECT: FIBERGLASS CONTAINERS FOR J-57 ENGINE

INVESTIGATOR: Harry E. Keller

CONTRACT: AF 01(608)832

CONTRACTOR: Fairchild Guided Missiles Division

ABSTRACT: Twenty fiberglass containers were manufactured for the Air Force to serve as shipping containers for the J-57 jet aircraft engine. The application of fiberglass for this purpose has proved successful with the exception of a liner sealing problem. The fiberglass container assembly weighs approximately 50% less than its metal counterpart, and testing has proved it to be rugged enough to withstand the rough handling it may receive in shipment.

The container consists of two shells, upper and lower, with the basic construction utilizing plies of bidirectional roving fabric impregnated with polyester resin. The sealing liner is made of rigid vinyl, thermoplastically drawn under vacuum into the shells. Provisions have been incorporated for fork lift, cable hoisting, rollover and stacking of the containers three high while in storage.

April 1959

SUBJECT: MATERIALS, TECHNIQUES, AND ECONOMICS OF FOAMED-IN-PLACE POLYURETHANE CUSHIONING FOR PACKAGING

INVESTIGATOR: Sidney Childers

ABSTRACT: This report describes an investigation into various aspects of foaming-in-place molded shapes of polyurethane cushioning material. The chemistry of the foam reactions and the foam systems are described. The aging characteristics of the materials and the effect on metals and humidity indicators of the vapors given off during foaming are discussed. Various facts about foaming methods and equipment are presented.

Of the foaming techniques investigated, it was found that completely premolding or a combination of premolding and foaming into the container was the best technique. It was also found that one can create molds by utilization of simple methods and low cost, reusable materials, such as hot melt plastics.

The cost of creating the molded shape is shown to be less, in most cases, than the present practise of procuring molded curled hair shapes.

March 1959

SUBJECT: INVESTIGATION OF DESIGN CRITERIA FOR CUSHIONING MATERIALS

INVESTIGATOR: Stewart M. Krakover, 1/Lt
Albert Olevitch

ABSTRACT: This report discusses the properties of cushioning materials significant for purposes of package cushioning design. Acceleration-static stress curves are the required dynamic property. It is shown that the minimum points of such curves reflect the most efficient operation of the cushioning materials. The other properties of significance are the static stress-strain and creep characteristics.

Examples of the application of the significant properties in designing package cushioning are presented. The economic aspects of utilizing cushioning materials are dependent on knowledge of these properties and a formula relating cost to the significant properties is presented.

The report also presents some design data on several different materials commonly available and the procedures for securing the design data. The report essentially is a text on the properties of cushioning materials and the design of package cushioning.

PLASTICS, STRUCTURAL

WADC TR 52-183, Sup 6
ASTIA Document No. AD 203784

October 1958

SUBJECT: ANNUAL REPORT ON RESEARCH FOR USE IN ANC-17 HANDBOOK
"PLASTICS FOR FLIGHT VEHICLES"
INVESTIGATOR: Donald G. Coleman
CONTRACT: AF 33(616)-56-9
CONTRACTOR: Forest Products Laboratory
ABSTRACT: Developments in the program of research in plastics for flight vehicles conducted by the U. S. Forest Products Laboratory during fiscal year 1958 are summarized. The approach has been in general to derive criteria mathematically and then to check by test. Three technical reports issued during the fiscal year are abstracted.

WADC TR 53-185, Part 5
ASTIA DOCUMENT NO. AD 212901

April 1959

SUBJECT: A STUDY OF EROSION OF AIRCRAFT MATERIALS AT HIGH SPEEDS
IN RAIN
INVESTIGATOR: Roy R. Lapp
Raymond H. Stutzman
Norman E. Wahl
CONTRACT: AF 33(616)-5455
CONTRACTOR: Cornell Aeronautical Laboratory, Inc.
ABSTRACT: This final report summarizes the results of comparative rain erosion tests on various types of materials for aircraft. The tests were conducted on the whirling arm test apparatus which simulates high speed flights through rain under controlled conditions. Flat and airfoil specimens fabricated from plastics or metals, with and without coatings, as well as ceramic materials were mounted on the leading edge of the whirling arm and evaluated for erosion resistance at 500 mph in 1 in/hr rainfall.

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In the tests on elastomeric coatings, an anti-static radome coating system developed by the Gates Engineering Company was recommended for approval under Class II of Specification MIL-C-7439B. The coating system consisted of N-15 primer, N-79 neoprene and a thin Gates anti-static surface coating.

In another group of tests it was observed that the erosion resistance of neoprene coatings approved under Class I of the specification, was significantly lower after exposure to gamma radiation at dosage levels of 5 to 35 megareps.

Preliminary tests indicate that the erosion resistance of standard neoprene coatings was increased about three-fold when the neoprene was treated with an antiozonant solution, however, it is questionable whether this treatment of neoprene coatings would be practical for use under service conditions because the neoprene becomes soft and sticky.

Weathering tests in Florida, Panama and Wisconsin indicated that the erosion resistance of standard Goodyear 23-56, Gaco N-79 neoprene coatings and an experimental white radome coating developed by Gates Engineering Company were reduced substantially at each location after one year outdoor exposure.

Initial studies indicate that the rain erosion resistance of recently developed thermoplastic polycarbonate laminates is better than polyester or epoxy laminates.

In collaboration with the National Bureau of Standards, various tests were conducted to study the mechanism of rain erosion and to improve the erosion resistance of currently used materials.

Methods of trying to combine the water of crystallization of chrysotile asbestos fibers so as to improve the strength retention of laminates exposed to temperatures of 900° - 1000°F were investigated. In general, most asbestos fiber treatments tended to degrade the fiber making them brittle and lower in strength. In this work it was found that the use of silane finishes A-1100 and A-172 on 9526 asbestos felt gave laminates with higher flexural strength at room temperature when used with DC-2104 and DC-2106 silicone resins.

WADC TR 53-192, Part 12
ASTIA Document No. AD 155756

July 1958

SUBJECT: MECHANISM OF RAIN EROSION, PART 12. PITS IN METALS
CAUSED BY COLLISION WITH LIQUID DROPS

WADC TR 53-373 Sup 6

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INVESTIGATOR: Olive G. Engel
CONTRACT: AF 33(616)-57-12
CONTRACTOR: National Bureau of Standards
ABSTRACT: An equation is presented that may provide a means of predicting corresponding-velocities-for-equal-pit-depth for collisions of metal specimens with drops of mercury and with drops of water. The purpose for determining such corresponding velocities is to provide a relatively low velocity test using high density liquid drops to determine the ability of materials of this kind to withstand damage as a result of collision with waterdrops at very much higher velocities.

WADC TR 55-186, Part 4
ASTIA Document No. AD 155647

June 1958

SUBJECT: ASBESTOS FIBER-REINFORCED PLASTIC LAMINATES
INVESTIGATOR: Charles L. Rohn
CONTRACT: AF 33(616)-2257
CONTRACTOR: Johns-Manville Corporation
ABSTRACT: The use of short fiber asbestos paper as a reinforcement in low pressure laminating resins has been investigated. The results of this investigation, based primarily upon mechanical properties of laminates at room temperature, are recorded in WADC Technical Reports 55-186, Parts I, II, and III.

The context of this report, a continuation of the former investigation, emphasizes high temperature strength properties and strengths of the laminates after exposure to wet conditions. A specific heat-resistant phenolic resin combined with the same asbestos reinforcement was used in this study.

The optimum strength properties of these asbestos laminates are dependent upon the fabricating techniques used. Variables such as laminating pressure, time and temperature, pre- and post-cure, and resin content have considerable effects upon the final properties of the laminate. Most of these techniques were developed during earlier work on asbestos laminates and were adopted for this investigation.

WADC TR 57-182
ASTIA Document No. AD 155884

September 1958

SUBJECT: PROPERTIES OF ALKYD-ISOCYANATE FOAMED-IN-PLACE CORE
INVESTIGATOR: P. M. Jenkinson
E. W. Kuenzi
CONTRACT: DO 33(616)56-9
CONTRACTOR: Forest Products Laboratory

WADC TR 53-373 Sup 6

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ABSTRACT: This report presents the results of flatwise compression, flatwise tension, shear, and a few flexure tests of sandwich consisting of facings of 0.03-inch-thick, glass-fabric laminate with a core of 0.50-inch-thick, alkyd-isocyanate foam. Test specimens and methods of test are described. Mechanical properties were evaluated at 75° and 160° F. for cores with densities of 10 and 20 pounds per cubic foot. These properties are presented in tables 1 and 2. Core strength decreased markedly as temperatures increased. Flatwise compressive strength at 160° F. was only 60 percent of that at 75° F. Exposure of the core to high humidity reduced the modulus of elasticity to 60 percent of the normal value. Flatwise compression stress-strain curves show that stresses at 2 percent core strain were about three-fourths those obtained at 10 percent head movement. The results of tests to determine moisture sorption and dimensional change for core material immersed in water and for core material exposed to 100 percent relative humidity at 100° F. are also included. Curves illustrate the variation of percentage changes of these properties with time. Moisture sorption as much as 2.5 percent and changes in dimensions up to 1.2 percent were observed for the core exposed to high humidity.

WADC TN 58-222
ASTIA Document No. AD 203526

October 1958

SUBJECT: EVALUATION OF THE SPLIT-LINE OPTICAL DISTORTION TEST METHOD

INVESTIGATOR: Robert N. Smith, Captain, Technical Photographic Division
John R. Meyer, 1/Lt.

ABSTRACT: The results of an evaluation of the split-line technique for photographically determining optical distortion in aircraft transparencies are presented. These results show that the split-line method is not operationally simple, is unreliable, and biased. The time consuming task of evaluating a photograph for split lines would probably more than offset any gain obtained by devising a set-up for fast, routine operation.

Since the final acceptance of a transparency is by visual inspection, it is concluded that the most necessary item to be determined is a criterion of acceptance on the basis of visual examination.

WADC TR 58-285
ASTIA Document No. AD 202500

October 1958

SUBJECT: DEVELOPMENT OF HIGH MODULUS FIBERS FROM HEAT RESISTANT MATERIALS

INVESTIGATOR: Albert H. Lasday

WADC TR 53-373 Sup 6

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CONTRACT: AF 33(616)-5263
CONTRACTOR: Houze Glass Corporation
ABSTRACT: This report deals with the development of new glass fiber forming compositions in order to produce high temperature continuous fiber monofilaments having high modulus of elasticity and strength. These properties need to be maintained at least to 1000°F. The most important objective is to produce a glass fiber whose elastic modulus divided by specific gravity is at least 9 million psi.

In order to develop such a glass fiber, the realm of metal oxide compositions melting at temperatures beyond 3,000°F must be investigated since the composition variables below 3,000°F (the region of conventional refractories and glass melting) already have been well explored. Furthermore, several high melting temperature oxides, some known to be glass producers, are also high modulus materials in bulk polycrystalline form.

Fiberization of these high temperature melting materials involves the development of new techniques. Two promising approaches have been developed. In the first, a glass rod of the high melting composition was made by dropping molten glass from a batch rod melting in a ring burner into a graphite mold. This glass rod was then heated inside a tubular graphite susceptor in an inductor coil, and when the glass reached the right temperature, a fiber could be drawn. The second approach involves drawing a fiber from a horizontal refractory cone, made of the same material as the batch rod. The cone is also heated in a graphite inductor. Molten glass droplets are melted from a batch rod using a ring burner and allowed to drop onto a concave cup in the upper surface of the cone.

Using an alumino-silicate composition based on kaolin, test fibers were made which gave indication of high elastic modulus. Some fibers tested as high as 19 million psi, although the data exhibits great scatter due to the crude way in which fibers were prepared.

WADC TR 58-298
ASTIA Document No. AD 203643

October 1958

SUBJECT: EXPLORATORY INVESTIGATION OF INORGANIC FIBER REINFORCED
INORGANIC LAMINATE FINAL REPORT
INVESTIGATOR: George Margo
CONTRACT: AF 33(616)-5251
CONTRACTOR: Goodyear Aircraft Corporation
ABSTRACT: Since the upper temperature limit of fiber-reinforced, organic- or silicone-bonded laminates is approximately 650 F for long time exposure, this program was initiated to explore the potential of inorganic materials for extending the thermal limit of structural laminates. The

evaluation was based on the fabrication and testing of laminates. Glass and asbestos were used as the primary reinforcement, but some preliminary work was done with a high-silica glass. The cements evaluated included sodium silicate, potassium silicate, calcium aluminate, polymeric silicic acid sol, magnesium oxysulphate, ethyl silicate, and aluminum phosphate.

This report describes the fabrication and testing of the laminates and includes a tabulation of laminate properties and test results. The main objective was the development of a laminate of structural integrity that would meet a stated target flexural strength at 1000 deg F after 10 hr at 1000 deg F. Although good structures were produced, it was determined that improvements in both reinforcement and cement are necessary to achieve the program goals.

WADC TR 58-356
ASTIA Document No. AD 202503

October 1958

SUBJECT: FIBER-RESIN BOND IN REINFORCED PLASTICS

INVESTIGATOR: Charles B. Norris
James T. Heller

CONTRACT: DO 33(616)56-9

CONTRACTOR: Forest Products Laboratory

ABSTRACT: A technique is developed for determining the rigidity of the bond between reinforcing strands of glass fibers and the resin in which they are embedded. This technique involves a method of accurate determination of the tensile stiffness of the strands; a method of casting small beams of resin reinforced with glass strands that are concentrated near one edge; an accurate method of testing such beams centrally loaded so as to induce shear between the strands and the resin; and a method of calculating the shear force on the strands, the bending stiffness from the test, and the expected bending stiffness if the bond is infinitely rigid. Comparison between the calculated stiffness of the beam and its test value in bending yields a measure of the shear rigidity of the bond between the strands and the resin.

This technique is described in detail, and some results are given for Epon 828 resin reinforced with glass strands that consist of 204 individual filaments, each about 0.00038 inch in diameter. The filaments were finished with starch-oil or A-1100 finish or heat-cleaned.

WADC TR 58-486
ASTIA Document No. AD 210225

March 1959

SUBJECT: EFFECTS OF VARIOUS METHODS OF WET CONDITIONING ON THE
STRENGTH PROPERTIES OF SEVERAL GLASS-FABRIC-REINFORCED
PLASTIC LAMINATES

WADC TR 53-373 Sup 6

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INVESTIGATOR: Bert P. Munthe
Robert L. Youngs
CONTRACT: DO 33(616)-58-1
CONTRACTOR: Forest Products Laboratory
ABSTRACT: This report presents the results of tests to evaluate the effects of various types and durations of wet exposure on the tensile, compressive, and flexural properties of epoxy, polyester, phenolic, and silicone laminates reinforced with 181 glass fabric that had various types of fabric finish. The tests were made after normal conditioning and after various periods of wet exposure. Wet conditions used were (1) immersion in water at 73°F., (2) exposure to an atomosphere at 100° F. and approximately 100 percent humidity, or (3) boiling in water.

Tensile strengths were reduced about equally by 30 days in water at 73° F. or by 2 hours in boiling water. Compressive strengths were reduced about the same amount by either 2 hours in boiling water, 30 days in water at room temperature, or 30 days at high humidity. Modulus of rupture was reduced about equally by equal periods of immersion in water at room temperature or exposure to high humidity at 100° F. At either of these conditions, the reduction after 30 days was generally similar to that observed after exposure in boiling water for 1/2 or 1 hour, but was generally less than that observed after exposure for 2 hours in boiling water.

The various laminates differed considerably in their response to the various wet exposure conditions. However, the results indicate that a 2-hour wet exposure in boiling water is a reasonable substitute for the standard 30-day immersion in water at room temperature. Any discrepancy is likely to be on the conservative side, with greater strength reduction after the 2-hour period in boiling water than after 30 days in water at room temperature.

WADC TR 58-555
ASTIA Document No. AD 212560

April 1959

SUBJECT: REVIEW OF STRUCTURAL PLASTICS
INVESTIGATOR: Robert C. Tomashot
ABSTRACT: This report is a compilation of papers presented at the Wright Air Development Center-University of Dayton joint review on Structural Plastics, 10 - 11 September 1958, Dayton, Ohio. The papers, for the most part, reviewed work completed or in progress under Materials Laboratory research and development contracts.

April 1959

SUBJECT: QUALITY IMPROVEMENT IN GLASS-FIBER-REINFORCED PLASTIC
STRUCTURAL DIELECTRICS FOR HIGH-FREQUENCY ANTENNAS
INVESTIGATOR: Henry J. Sang
CONTRACT: AF 33(616)-3997
CONTRACTOR: Stanford Research Institute
ABSTRACT: An accelerated version of the Rangoon test condition,
simulating a humid tropical climate, was developed for plastic laminates.
Four different types of material were evaluated in the Rangoon condition
and in eighteen different accelerated conditions. The best of the acceler-
ated conditions was AR-9, which produced in twelve days effects similar to
those produced by the Rangoon test in 120 days. The AR-9 test condition
is recommended as a replacement for the present water-immersion and boil
tests.

An exploratory study was made of quality control of
Vibrin 136 A resin for high-temperature use. Twenty-three different var-
ieties of laminate were made and tested for strength and strength retention
at 500°F. The strength properties were found to vary greatly with the
manner of processing and curing. Representative varieties of laminate
were resistant to deterioration in the accelerated Rangoon condition.
The most critical aspect of the resin is its tendency to blister during
post-curing; until this problem is solved, effective quality control
cannot be secured. The best laminate made had a strength of 42,700 psi
in flexure at 500°F after 192 hours aging at 500°F.

May 1959

SUBJECT: EVALUATION OF LAMINATES REINFORCED WITH CHEMICALLY
CLEANED AND FINISHED LOW-DIELECTRIC GLASS FABRIC
INVESTIGATOR: Gordon H. Stevens
CONTRACT: DO 33(616)-58-1
CONTRACTOR: Forest Products Laboratory
ABSTRACT: This report presents evaluations of mechanical and
electrical properties of laminates reinforced with 181 glass fabric that
had been chemically cleaned before finish was applied. Each laminate was
made of Paraplex P-43 resin reinforced with (1) 181-Volan A standard "E"
glass fabric, (2) 181-Volan A low-dielectric glass fabric, (3) 181-Garan
low-dielectric glass fabric, or (4) 181-NOL 24 low-dielectric glass fabric.
The mechanical properties of 2 epoxy laminates of Epon 828 resin and 181-
Volan A glass fabric -- one of standard "E" glass and the other of low-
dielectric glass -- were also evaluated.

Laminates reinforced with chemically cleaned low-dielectric glass fabric were lower in mechanical properties than similar laminates reinforced with heat-cleaned glass fabric. The polyester Volan A laminates of chemically cleaned low-dielectric glass fabric were between 50 and 60 percent as strong as the corresponding laminates of heat-cleaned low-dielectric glass fabric. The strength ratio of the epoxy laminates was between 70 and 85 percent. A polyester laminate made of chemically cleaned low-dielectric glass fabric had about 30 to 45 percent of the strength of the comparable laminate made of heat-cleaned "E" glass fabric. The strength of the heat-cleaned low-dielectric laminate, however, was 50 to 85 percent of that for the laminate of heat-cleaned "E" glass fabric. The polyester laminate reinforced with chemically cleaned "E" glass fabric was 2 and 11 percent stronger in tension and compression, respectively, and 5 to 13 percent weaker in dry and wet flexural strength, than the similar laminate of heat-cleaned "E" glass fabric.

Comparative values from 181-Volan A polyester laminates indicate that laminates made with chemically cleaned fabric have poorer electrical properties than comparable laminates made with heat-cleaned fabric. The dielectric constants were about 10 percent greater and the loss tangents 4 to 6 times as large for the laminate of chemically cleaned low-dielectric glass fabric. The dielectric constants were about 15 to 25 percent larger for laminates of standard "E" glass fabric than for laminates of comparable low-dielectric glass fabric. The loss tangents for laminates of chemically cleaned low dielectric glass fabric were 3 to 4 times those for laminates of both heat-cleaned and chemically cleaned "E" glass fabric. The loss tangents for laminates of heat-cleaned low-dielectric glass fabric, however, were about 30 percent lower than those for laminates of "E" glass fabric. The dielectric constants were 3 percent lower and the loss tangents about 20 percent lower for laminates of heat-cleaned "E" glass fabric than for laminates of chemically cleaned "E" glass fabric.

POLYMERS AND SYNTHESIS STUDIES

WADC TR 55-221 Part 5
ASTIA Document No. AD 212902

April 1959

SUBJECT: FLUORINE-CONTAINING CONDENSATION POLYMERS AND RESINS
INVESTIGATOR: Carl J. Verbanic Edward V. Gouinlock
David Knutson C. Thomas Bean
John E. Wier

CONTRACT: AF 33(616)-5548

CONTRACTOR: Hooker Chemical Corporation

ABSTRACT: The ultimate goal of the investigations described is the determination of the effect of fluorine and fluorine content on the thermal and oxidative stability of unsaturated polyester laminating resins. An additional function is to aid in the investigations of the perfluorinated amadine polymers currently of interest to Wright Air Development Center.

Polyesters and polyester resin laminates have been prepared using fluorinated glycols as a component of the polyester. The laminates have been aged at elevated temperatures and physical properties measured before and **after** aging. Comparison of these aging results with polyesters containing hydrocarbon glycol components of the same carbon chain length indicate a noticeable improvement in retention of physical properties of the fluorinated materials over the hydrocarbon analogues.

The report also describes the research performed on the preparation of certain fluorine-containing compounds for use as starting materials for the preparation of polyesters and cross-linking monomers.

A new and improved synthesis of perfluoroglutaronitrile is described and efforts to improve the yields of the dehydration of perfluoroglutaramide are given.

Research on the synthesis of certain novel or unusual fluoride-containing intermediates considered desirable for polymerization in this project was performed at Purdue University under sub-contract to Hooker Chemical Corporation. Details of the syntheses performed at Purdue during the contract year comprise Appendix I of this report.

WADC TR 56-203 Part III
ASTIA Document No. AD 155525

May 1958

SUBJECT: COORDINATION POLYMERS

WADC TR 53-373 Sup 6

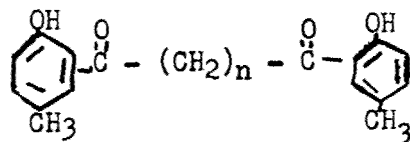
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INVESTIGATOR: W. Conard Fernelius B. B. Martin
 Maurice Shamma D. F. Martin
 L. A. Davis F. D. Thomas, II
 D. E. Goldberg
 CONTRACT: AF 33(616)-2742
 CONTRACTOR: The Pennsylvania State University
 ABSTRACT: As part of a study of the influence of structural variation on the properties of bis(β -diketones) and their metal derivatives, compounds of the following types have been prepared: (1) $\text{RCOCH}_2\text{CO-Y-COCH}_2\text{COR}$, (2) $[(\text{R}'\text{CO})(\text{RCO})-\text{CH}]_2\text{CHR}''$ and (3) $(\text{RCO})(\text{R}'\text{CO})\text{CH-Y-CH}(\text{COR}')(\text{COR})$. The methods of syntheses of these compounds have been studied. Compounds of types (2) and (3) offer the best promise of obtaining wide structural variation. Efforts to obtain bis-(β -diketones) containing fluorine atoms have failed, although some of the methods used have been successful when applied to other systems. The infrared and ultraviolet absorption spectra of various bis(β -diketones) have been obtained.

Various modifications of the polymerization techniques are being studied in an attempt to obtain high-molecular-weight polymers from the bis(β -diketones). Methods for fractionally separating polymers in order to get some idea of size distribution promise to be successful with the bis(β -diketone)-metal polymers.

The Fries rearrangement of di-*p*-tolyl esters has been studied as a means of preparing bis(α -hydroxyketones). As a result, di-*p*-tolyl esters have been prepared from succinic acid through and including sebacic acid, diglycolic acid, and phthalic, isophthalic and terephthalic acids.

The esters from succinic acid through and including sebacic acid were successfully rearranged (Fries rearrangement) to their corresponding bis-(α -hydroxyketone):



where *n* equals 2 to 8. The rearrangement was unsuccessful for di-*p*-tolyl-diglycolate. The rearrangement of the di-*p*-tolyl esters of isophthalic and terephthalic acids led to the formation of their corresponding bis(α -hydroxyketones). Attempted rearrangement of di-*p*-tolyl phthalate resulted in the formation of 1-hydroxy-5-methylanthraquinone. The infrared absorption spectra of the various bis(α -hydroxyketones) have been obtained.

In an attempt to prepare 5-acyl compounds of 8-hydroxyquinoline by the Fries rearrangement of 8-hydroxyquinoline esters, the following esters were prepared: 8-hydroxyquinolylacetate, propanoate, butanoate, benzoate, and adipate. The Fries rearrangement of the 8-hydroxyquinoline esters was unsuccessful.

Preparation of 5-acyl derivatives of 8-hydroxyquinoline by means of the Friedel-Crafts reaction (8-hydroxyquinoline, acid chloride, aluminum chloride) appears quite promising. 5-Acetyl-8-hydroxyquinoline has been prepared in 27% yield. 5-Benzoyl-8-hydroxyquinoline and 5-propanoyl-8-hydroxyquinoline have also been prepared.

WADC TR 57-143 Part III
ASTIA Document No. AD 212268

April 1959

SUBJECT: DEVELOPMENT OF THERMALLY STABLE SILICON CONTAINING RESINS
INVESTIGATOR: L. W. Breed
William J. Haggerty, Jr.
Fred Baiocchi
CONTRACT: AF 33(616)-3675
CONTRACTOR: Midwest Research Institute
ABSTRACT: The syntheses and evaluation of new monomers for incorporation into silicon containing resins are reported. The new monomers, which are mostly based on the arylenedisilane structure, are selected for use in establishing polymeric units capable of imparting good high temperature properties to silicone resin systems.

The new monomers include compounds which contain two or more silicon atoms separated by various space groups. Described in the report are the following compounds: $\text{Me}(\text{EtO})_2\text{SiYSi}(\text{EtO})_2\text{Me}$ where Y is $-\text{C}_6\text{H}_4\text{C}_6\text{H}_4-$, $-\text{C}_6\text{H}_4\text{CH}_2-$, and $-(\text{CH}_2)_6-$. Other monomers are prepared which have different substituents on the organic group not used as a spacer. These monomers include the following: $\text{YC}_6\text{H}_4(\text{EtO})_2\text{SiC}_6\text{H}_4\text{Si}(\text{EtO})_2\text{C}_6\text{H}_4\text{Y}$ where Y is H-, Cl-, MeO-, and Me₂N-. The method of synthesis and properties of each new monomer is described in detail.

Silicone-glass fabric laminates are described which contain disilylbenzene monomers and have improved flexural strengths at temperatures above 500°F. The results of screening new resins and investigating the composition and fabrication parameters in these new resin systems are included. These results are obtained by a procedure which requires relatively small amounts of experimental resin.

May 1959

SUBJECT: SYNTHESSES OF POLYXYLYLYLDIMETHYLSILANE AND
POLYXYLYLYLTETRAMETHYL SILOXANE
INVESTIGATOR: Glenn R. Wilson Richard C. Hetu
Gretchen M. Hutzell Arthur G. Smith
CONTRACT: AF 33(600)-32448
CONTRACTOR: Ford Motor Company
ABSTRACT: The purpose of this project is the synthesis of a series
of poly-p-xylylyldimethylsilanes and poly-p-xylylyltetramethylsiloxanes
for evaluation as high temperature lubricants and/or hydraulic fluids.

At the time of the last annual report (WADC TR 57-321, Part II), and after numerous unsuccessful attempts to prepare the basic building unit, bis (trimethylsilyl)-p-xylylene, of these proposed polymers, a successful procedure was developed while investigating the preparation of the meta isomer. As a result we were able to prepare the o-, m-, and p-isomers of bis (trimethylsilyl) xylylene and by the same technique a difunctional intermediate, bis (dimethylchlorosilyl)-p-xylylene that could be used for preparing the polysilane or polysiloxane.

Synthesis of the polysiloxane was selected as the first choice due to the fact that a homogeneous-type polymer was anticipated, whereas, a heteropolymeric chain was anticipated in preparing the polysilane due to the undesirable coupling of xylylene dihalides to bibenzyl moieties in the reaction.

Several small-scale polymerizations of bis (dimethylchlorosilyl)-p-xylylene, in the presence of variable quantities of trimethylchlorosilane, with water were carried out and the polymers obtained were of relatively low molecular weight, ca. 700-1100. Results of copolymerization with p-bromophenyldimethylchlorosilane, to provide analyzable end groups, indicated that the polymer contained a high percentage of cyclic polymer.

Since the project is being terminated, a series of runs for preparing bis (dimethylchlorosilyl)-p-xylylene were made and the yields combined to provide a sizeable quantity. Some 600 grams of the intermediate has been prepared and polymerized with trimethylchlorosilane to provide a sufficient quantity of the polysiloxane for evaluation.

June 1958

SUBJECT: THE AIR FORCE INORGANIC POLYMER PROGRAM

INVESTIGATOR: Robert L. Rau, 1/Lt
ABSTRACT: The purpose of this report is to critically review and evaluate the Air Force inorganic polymer program carried on by various organizations under contract to the Materials Laboratory, Wright Air Development Center, Air Research and Development Command.

Because of the thermal limitations of "organic polymers", efforts have been directed toward the preparation of polymeric materials having varying degrees of inorganic character. Various boron, nitrogen and phosphorus containing polymers have been investigated in addition to coordination polymers and those incorporating the silicon-oxygen-metal bond.

The results obtained have been partially successful. Boron-phosphorus polymers having stabilities as high as 450°C and coordination polymers stable in excess of 360°C in air have been prepared by contractors, although they did not have useful properties due to low molecular weights. Continued success is strongly dependent upon the development of methods for obtaining high molecular weights, as well as the development of analytical procedures for determining molecular weights for these types of polymers.

WADC TR 58-187 Part I
ASTIA Document No. AD 155737

July 1958

SUBJECT: SYNTHESIS AND EVALUATION OF HIGH TEMPERATURE STABLE AND NUCLEAR RADIATION STABLE METAL-CYCLOPENTADIENYL FLUIDS
INVESTIGATOR: Robert L. Schaaf
Kenneth L. Rinehart, Jr.
CONTRACT: AF 33(616)-5053
CONTRACTOR: Wyandotte Chemicals Corporation
University of Illinois

ABSTRACT: In a search for fluids suitable for use as Air Force high-temperature hydraulic fluids and lubricants, four 1,1'-bis(3-substituted-1,1,3,3-tetramethyldisiloxanyl)-ferrocenes were synthesized from cyclopentadiene via cyclopentadienyldimethylchlorosilane and a series of 1-cyclopentadienyl-3-substituted-1,1,3,3-tetramethyldisiloxanes. The 3-phenyl compound possessed the desired thermal stability at 366°C (690°F). Other previously unreported ferrocenes and intermediates synthesized included 1,3-bis(cyclopentadienyl)-1,1,3,3-tetramethyldisiloxane, 1,3-(1,1'-ferrocenylene)-1,1,3,3-tetramethyldisiloxane, 1-cyclopentadienyl-3-chloro-1,1,3,3-tetramethyldisiloxane, and 1-cyclopentadienyl-5-phenyl-1,1,3,3,5,5-hexamethyldisiloxane.

Experiments designed to elucidate the structures of products from the condensation of ferrocene with formaldehyde and benzaldehyde were performed, and a number of intermediates required for a study of the formation of bridged ferrocenes were synthesized.

Additional areas of investigation which were studied but largely without success included the syntheses of alkoxy cyclopentadienes, the preparation of 3-methyl-1-ethylcyclopentadiene, and the identification of liquid ferrocenes by means of adducts of ferrocenes and tetranitrofluorenone.

WADC TR 58-219
ASTIA Document No. AD 155658

June 1958

SUBJECT: SYNTHESIS OF DIFUNCTIONAL FERROCENE DERIVATIVES

INVESTIGATOR: Paul D. Shaw, 1/Lt William S. Durrell,
Dana Mayo, 1/Lt Myron Black, 2/Lt
Marvin Rausch, 1/Lt Dr. A. M. Lovelace

ABSTRACT: This program was undertaken to investigate the synthesis of difunctional ferrocene compounds for use as monomers. A number of ferrocene diols were prepared. Several methods for the synthesis of the ferrocene carboxylic acids were investigated. An improved synthesis of ferrocene dicarboxylic acid has been achieved using *n*-butyllithium in a solvent system consisting of diethyl ether and tetrahydrofuran.

WADC TR 58-377
ASTIA Document No. AD 207526

January 1959

SUBJECT: RELATIONS BETWEEN STRUCTURE AND RADIATION STABILITY OF
VARIOUS ALKYL AROMATIC FLUIDS

INVESTIGATOR: Josef J. E. Schmidt Francis S. Bonomo
Don N. Gray James G. Pomonis

CONTRACT: AF 33(616)-5317

CONTRACTOR: Denver Research Institute

ABSTRACT: The effects of gamma radiation from a Cobalt-60 radiation source on liquid alkyl derivatives of biphenyl and terphenyl compounds have been investigated and the type and yield of gaseous decomposition products determined. The counter-current distribution method was found to be the most feasible means of separation of liquid irradiation products.

Alkyl substituted diphenyl and polyphenyl derivatives show a relatively high radiation stability. The influence of the type of alkyl substituent and its position on the molecule indicates an energy transfer mechanism. This mechanism is to be investigated in more detail in the remaining research period.

WADC TR 53-373 Sup 6

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November 1958

SUBJECT: SYNTHESIS AND EVALUATION OF NEW POLYMERS PREPARED BY STEREOSPECIFIC CATALYSIS

INVESTIGATOR: Charles G. Overberger

CONTRACT: AF 33(601)-5253

CONTRACTOR: Polytechnic Institute of Brooklyn

ABSTRACT: Pure cis or trans 3 and 4-methylvinylcyclohexane have been prepared. The polymer obtained from the triisobutyl aluminum-titanium tetrachloride catalyzed polymerization of 3-methylvinylcyclohexane was crystalline. Vinylcyclopentane has been synthesized and polymerized with a triisobutyl aluminum-titanium tetrachloride catalyst; and polyvinylcyclopentane was found to be crystalline. Methylenecyclohexane and methylenecyclopentane were made, and these olefins failed to polymerize with a Ziegler-Natta type catalyst. Methylenecyclobutane was synthesized and polymerized, apparently with some ring opening with a Ziegler-Natta type catalyst. 3,3,3-Trifluoropropene was prepared and failed to polymerize with a triisobutyl aluminum-titanium tetrachloride catalyst. The preparation of 4,4,4-trifluorobutene-1 has been carried out. 1,4-Pentadiene was obtained from the pyrolysis of 1,5-pentamethylene diacetate.

A kinetic study of the polymerization of vinylcyclohexane with a triisobutyl aluminum-titanium trichloride catalyst showed that both oxygen and water effect the rate of polymerization. Unit cell dimensions were determined for crystalline polyvinylcyclohexane and crystalline polyvinylcyclopentane.

RARE METALS

WADC TR 57-666 Part I
ASTIA Document No. AD 155685
OTS Release

June 1958

SUBJECT: SELECTION AND EVALUATION OF RARE OR UNUSUAL METALS FOR APPLICATION TO ADVANCED WEAPONS SYSTEMS
PART I. A LITERATURE SURVEY

INVESTIGATOR: Bernard Love

CONTRACT: AF 33(616)-5293
CONTRACTOR: Research Chemicals Inc.
ABSTRACT: A survey has been made of the unclassified literature relating to the rare earth elements, hafnium, rhodium, and ruthenium. The best available data has been compiled for the abundance and distribution of elements, the methods of recovery from ores and purification, the reduction to metal, and the physical, chemical, and mechanical properties of the elements and their important compounds.

WADC TR 57-666 Part II
ASTIA Document No. AD 211847
OTS Release

March 1959

SUBJECT: SELECTION AND EVALUATION OF RARE OR UNUSUAL METALS
PART II. THE METALLURGY OF YTTRIUM AND THE RARE EARTH METALS
INVESTIGATOR: Bernard Love
CONTRACT: AF 33(616)-5905
CONTRACTOR: Research Chemicals Inc.
ABSTRACT: Studies have been made of the properties of yttrium and the rare earth metals. These have included metallographic studies, oxidation and corrosion resistance studies, mechanical property determination and studies of alloys of titanium and beryllium with rare earth additions.

Improved methods for the production of pure metals are described. A complete metallographic procedure has been developed. Procedures for the chemical and spectrographic analysis of metals and alloys are provided including a method for oxygen analysis.

Corrosion studies include determination of the rate of moisture absorption of the rare earth oxides under controlled conditions of temperature and humidity, and determination of the rate of atmospheric corrosion of the metals in dry and humid atmospheres at 35 and 95°C, and at 200, 400, and 600°C. The rate of atmospheric corrosion was found to vary widely; from europium, a fresh surface of which starts to oxidize immediately on exposure to air, to samarium for which oxidation was very slow even at the elevated temperatures.

Mechanical properties of cast and wrought rare earths are presented for both room and elevated temperatures. Tensile properties vary widely. Yttrium and the heavy rare earths appear to have the best mechanical properties, and maintain a considerable percentage of room temperature strength to temperatures of 427°C (800°F).

The methods of preparation, analysis, and examination of titanium and beryllium alloys containing up to 10% rare earth elements are presented. Tentative partial constitutional diagrams are constructed. Very low solubility was found except for lanthanum which had an indicated solubility between 0.2 and 1.5 weight percent.

RUBBER

WADC TR 55-58 Part IV
ASTIA Document No. AD 206077

November 1958

SUBJECT: A STUDY OF THE EFFECTS OF NUCLEAR RADIATIONS ON ELASTOMERIC COMPOUNDS AND COMPOUNDING MATERIALS

INVESTIGATOR: John W. Born

CONTRACT: AF 33(616)-2308

CONTRACTOR: B. F. Goodrich Company

ABSTRACT: The research in this fourth year under the contract included the following: fundamental studies of the mechanism of radiation damage to high polymers and of the influence of molecular structure on the relative degree of radiation effects; basic attempts to protect textile filaments and cords from radiation damage; further screening of anti-rads for other conventional and newer elastomers; a search for and attempted synthesis of new and more effective anti-rads; applied studies of the separate and combined effects of heat and radiation on aircraft rubber compounds; irradiation and full-scale indoor testing of aircraft tires, with and without potential anti-rad protection; and formulation of a detailed program for the next end-item study, which will deal with "O" ring seals.

The work which is reported thus included fundamental, basic, applied, and end-item research. The results are stated very briefly in the following summary.

WADC TR 55-492 Part IV
ASTIA Document No. AD 213607

May 1959

SUBJECT: RESEARCH AND DEVELOPMENT ON HIGH TEMPERATURE FUEL RESISTANT RUBBER COMPOUNDS

WADC TR 53-373 Sup 6

INVESTIGATOR: Raymond G. Spain
Wayne G. Lajiness
Eva Deck
CONTRACT: AF 33(616)-5544
CONTRACTOR: Wyandotte Chemicals Corporation
ABSTRACT: This report describes research toward the development of elastomeric compounds resistant to high energy fuels (HEF) at elevated temperatures.

Initial screening tests in HEF at moderate temperatures indicated that of the available elastomers only certain fluoroclastomers were suitable for investigations at higher temperatures in HEF. Accordingly, compounding and HEF aging studies were concentrated on these materials.

The Micro Tester was completed during this report period. This device will permit the determination of the tensile properties of vulcanizates at temperatures up to 600°F, while the test specimens are immersed in test fluids.

The Dynamic O-Ring Test Apparatus was also completed during this report period. This device will be used to test experimental vulcanizates as O-ring seals for a reciprocating shaft at simulated use conditions.

As priority was given to the HEF aging studies, only a minor portion of the effort was directed toward the continued development of elastomeric compounds resistant to petroleum base fuels.

WADC TR 56-331 Part III
ASTIA Document No. AD 212903

April 1959

SUBJECT: DEVELOPMENT OF HIGH TEMPERATURE RESISTANT RUBBER COMPOUNDS
INVESTIGATOR: Robert A Hayes James C. Henning
Floyd M. Smith Jack D. Rigby
Glenn A. Kidder George L. Hall
CONTRACT: AF 33(616)-3953
CONTRACTOR: The Firestone Tire & Rubber Company
ABSTRACT: Heat-stable elastomers of potential interest for such applications as high temperature aircraft tires, ducting, seals, and flexible connectors were compounded to improve the physical properties required for construction and performance. Improved methacrylate rubber compounds were obtained by lowering the carbon black level; self-adhesion was improved at the expense of tensile strength by adding a small amount of Hevea rubber, and better building cements were developed. Improved "high-strength" silicone rubber compounds were obtained by replacing dichlorobenzoyl with di-t-butyl

peroxide and by limiting the postcure temperature to 450°F. Viton A stocks with improved scorch were obtained by adding Copper Inhibitor 65, but the best stocks are still stiff with poor self-adhesion and poor adhesion to wire at elevated temperatures. Poly (ethyl acrylate) compounds, cured with metal oxides were developed which show good high temperature properties and excellent dynamic properties.

Prototype wire tirecord aircraft tires were constructed from both methacrylate rubber and silicone rubber. Tires of both rubbers successfully withstood hydraulic tests at 210 psig but had wavy contours when inflated due to difficulties encountered during their construction.

Epoxy extended polyesters, capable of some degree of cure with peroxides, have been developed. Terpolymers of butadiene, acrylonitrile, and methyl acrylate cured with metal oxides gave 400°F tensile strengths as high as 1130 psi. Non-elastomeric polymers with outstanding thermal stability have been prepared from the reaction of diepoxides with diphenols. A graft polymer of methyl methacrylate on Hevea rubber did not give successful metal oxide cures.

WADC TR 58-89

June 1958

ASTIA Document No. AD 155606

SUBJECT: DEVELOPMENT OF HIGH TEMPERATURE SEALANTS
INVESTIGATOR: Irvin P. Seegman Sarkis H. Kalfayan
William Cheorvas Paul A. Mallard
Francis H. Ingham Ron E. Thompson
R. Loren Varner

CONTRACT: AF 33(616)-3976

CONTRACTOR: Products Research Company

ABSTRACT: A fill and drain sealant based on Viton A has been developed which has excellent resistance to fuels at 450°F. Good adhesion to stainless steel and titanium was obtained by use of a primer and was retained after exposure to fuel for 42 hours at 450°F, oven again 336 hours at 450°F and immersion in salt water for 168 hours at 140°F. The fill and drain system consists of a dilute solution of Viton A and phenolic resins as a primer, a Viton A sealant compounded with silicone coated silica and magnesium oxide at 28% solids in methyl isobutyl ketone and an amine curing solution.

An 80% solids filleting sealant with excellent resistance to fuel and dry heat at 450°F and adequate low temperature properties has been developed from Viton A cured with hexamethylene diamine. A phenolic primer provided satisfactory adhesion to stainless steel, while a dual primer system was required for titanium. The sealant can be cured adequately in one hour at 250°F but requires an additional 2 hours at 350°F to develop adhesion

A 100% solids filleting formulation based on PAH-1 was cured with benzoyl peroxide to an elastomeric material which had excellent resistance to Type III and JP-5 fuels at 350°F, but its initial tensile strength properties were not of a very high order. After these exposure conditions good adhesion was retained to stainless steel primed with either DC-A-4014 or a phenolic-triallyl cyanurate primer. Improved tensile strength properties were obtained with peroxide cured filleting formulations based on Viton A, LS-53 or 1F4 plasticized with either PAH-1 or reverted LS-53U, but good adhesion to stainless steel has not been obtained.

A groove sealant was developed which meets the 350°F and 450°F requirements of this contract. This sealant formulated from LS-53U and 1F4 maintained its seal and was capable of reinjection after 6 days immersion in Type II reference fluid or JP-4 fluid at 275°F followed by 7 days at 350°F or 2 days at 450°F with equally satisfactory results. The compound met the major requirements of the proposed 250°F Military Groove Sealant Specification and the sealing and reinjection requirements of this specification when tested at 350°F and 450°F.

Compounds have been developed which should be suitable for use as nonfuel resistant pressurization sealants for high temperature exposures to 700°F. Formulations are based on room temperature vulcanizing silicone compounds. For elevated temperature service a stepwise post cure up to the anticipated operating temperature is required. Higher temperature properties were outstanding. Physical properties were reasonable and adhesion was obtained at all temperatures with use of the proper primer.

Studies were made of the cure of various hexafluoropen-tylene adipate polymers with polyisocyanates, peroxides, tetra-alkyl titanates, aliphatic polyamines and sulfur. Cures were obtained only with polyisocyanates and peroxides. The materials thus obtained were either lacking in fuel resistance or required excessive temperatures for cure.

Cocuring of vinyl containing silicones with polymeric substances of known fuel resistance showed no promise and work in this direction was abandoned.

An inorganic polymer, phosphonitrilic chloride, has been polymerized to a rubbery mass. Several objectionable characteristics including its highly corrosive nature made it evident that this material was not suitable for sealants.

June 1958

SUBJECT: A DESIGN MANUAL FOR ELASTOMERS USED IN NUCLEAR ENVIRONMENTS
INVESTIGATOR: Richard G. Bauman
CONTRACT: AF 33(616)-2308
CONTRACTOR: The B. F. Goodrich Company
ABSTRACT: A design manual has been prepared which assembles the research information gathered by B. F. Goodrich scientists during the years 1954-1957. Only that material of interest to airframe design engineers has been included.

The primary topics included are the radiation resistance of a large group of rubber compounds to tensile changes; the dynamic property changes of a group of selected compounds when irradiated; the radiation resistance of practical aircraft compounds used in tires, hose, fuel cells, gaskets and packing; and the protection afforded by anti-rads.

March 1959

SUBJECT: RESEARCH AND DEVELOPMENT OF HIGH TEMPERATURE NUCLEAR RADIATION RESISTANT ELASTOMERS
INVESTIGATOR: O. M. Grace B. Hunt
P. Davis R. E. Isley
CONTRACT: AF 33(616)-5303
CONTRACTOR: Burke Research Company
ABSTRACT: The chief purpose of this work was the investigation of the effect of structure of elastomers on the resistance to change under gamma radiation.

Over three hundred and seventy polymers were prepared chiefly by heterogeneous catalysis, many of which polymers can not be prepared by other techniques. The monomers employed were chiefly olefins and diene hydrocarbons, and the most of the polymers prepared were elastomeric. Fifty of these polymers were selected for gamma irradiation (cobalt 60 source). A few plastomers were included in this number for comparison, as well as a number of emulsion polymers.

Catalyst systems were developed to copolymerize halo-substituted ethylenes with ethylene (e.g. vinyl chloride, vinylidene chloride and vinylidene fluoride) but fluoro-containing elastomers with interesting tensile properties were not yet attained.

Irradiation studies showed several contact polymers of relatively good resistance to irradiation: butadiene-styrene, butadiene-ethylene, butadiene-phenylbutadiene, and butadiene-alpha-methylstyrene. None were better than natural rubber with respect to decrease in elongation, but the phenyl and methyl groups in such polymers resulted in good retention of tensile strength and hardness in comparison with natural rubber.

WADC TR 59-42
ASTIA Document No. AD 211763

March 1959

SUBJECT: A ROOM TEMPERATURE VULCANIZATION SYSTEM FOR SELECTED FLUORINE-CONTAINING POLYMERS
INVESTIGATOR: Warren R. Griffin
ABSTRACT: The development of a room temperature vulcanization system for selected fluorine-containing polymers is described. A theory is postulated to explain the vulcanization involving attachment of reactive sites to the polymers at elevated temperatures followed by cross-linking through these sites at room temperatures. The formulation, characteristics and test data are given for a hexafluoropropylene-vinylidene fluoride copolymer (Viton A*) vulcanized by this system. The technique appears applicable to the preparation of sealants, aerodynamic smoothers and other related materials urgently required by the Air Force for advanced vehicles.

SANDWICH CONSTRUCTION

WADC TR 55-417 Part III
ASTIA Document No. AD 202492

October 1958

SUBJECT: PERFORMANCE OF BRAZED STAINLESS STEEL SANDWICH AT HIGH TEMPERATURES
INVESTIGATOR: W. E. Jahnke
E. W. Kuenzi
CONTRACT: DO 33- (616)56-9
CONTRACTOR: Forest Products Laboratory
ABSTRACT: This report presents results of tests to investigate structural performance of stainless steel sandwich comprised of facings brazed to honeycomb cores. Performance was determined at 75°, 800°, 1000°, and 1,200° F. after short-time exposure to test temperatures.

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Included in this report are comparisons between facing stresses actually developed in test specimens and stresses computed theoretically for sandwich that fails either by dimpling of facings into the core cells or by buckling when subjected to edgewise compression.

WADC TR 55-463 Part II
ASTIA Document No. AD 155725
OTS Release

July 1958

SUBJECT: DEVELOPMENT OF BRAZED SANDWICH CONSTRUCTION MATERIALS
FOR HIGH TEMPERATURE APPLICATIONS
INVESTIGATOR: Charles F. Burrows
F. J. Ragland, Jr.
CONTRACT: AF 33(616)-2602
CONTRACTOR: The Martin Company
ABSTRACT: An investigation was undertaken to study various base metal - braze alloy combinations for honeycomb sandwich structures that would have utility up to a maximum temperature of 1200°F. The base alloys, 17-7PH, 422, A 286, 19-9 DL and 17-14 Cu Mo were evaluated with silver and nickel base brazing alloys to determine their compatability and strength characteristics to develop an optimum sandwich combination.

On the basis of brazing studies and structural tests, it was found that A 286 corrosion resistant steel brazed with a nickel-chromium-silicon-iron-boron alloy offered the optimum sandwich construction for operating temperatures of 1000° to 1200° F.

Static flexure and edgewise compression data are given for all optimum base metal-braze alloy combinations. S/N curves for flexural fatigue studies made at temperatures of 75°, 500°, and 1000°F are presented for the A 286 with Ni-Cr-Si-Fe-B optimum sandwich combination.

WADC TR 58-172
ASTIA Document No. AD 155805

August 1958

SUBJECT: EFFECT OF VOIDS IN GLASS-FABRIC-REINFORCED
SANDWICH FACING
INVESTIGATOR: B. G. Heebink
K. E. Kimball
R. A. Hann
CONTRACT: DO 33(616)-56-9
CONTRACTOR: Forest Products Laboratory

WADC TR 53-373 Sup 6

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ABSTRACT: Two sets of composite plastic sandwich panels were fabricated. One set was constructed with premolded, relatively void-free faces and the other was wet laminated, which caused numerous small voids.

Compression tests showed that the panels with void-free, premolded faces were substantially stronger than the wet-laminated panels. Electrical tests showed that although both types passed the minimum electrical transmission specification requirements, exposure to temperature and humidity cycling resulted in practically no change from 100 percent transmission for the premolded panel, whereas the wet lay-up construction was borderline in passing the requirement under the same exposure conditions.

SOLID FILM LUBRICANTS

WADC TR 58-499
ASTIA Document No. AD 207795
OTS Release

January 1959

SUBJECT: THE EFFECTS OF NUCLEAR RADIATION ON SOLID FILM
LUBRICANTS

INVESTIGATOR: William L. R. Rice
William L. Cox, 1/Lt

ABSTRACT: The effect of nuclear radiation on twelve commercial solid film lubricants was determined. The lubricants were typically phenolic or epoxy resin bonded, incorporating graphite or molybdenum disulfide. Gamma exposures covered the range 8.71×10^9 through 2.61×10^{11} ergs per gram carbon. Neutron exposures were over the range 1×10^{15} to 3×10^{16} nvt fast.

Data were obtained on the wear life, corrosion resistance, fluid resistance, and thermal stability. It was observed that radiation, in certain instances, improved wear life rather than decreasing it. Also, those solid films that possessed good corrosion and fluid resistance and good thermal stability prior to irradiation generally were not seriously changed in these properties. Films of poor initial properties were greatly degraded by the radiation.

It was concluded that certain of the films should be useable up to the maximum dosages used, but that careful selection would be necessary.

TESTS, NONDESTRUCTIVE

WADC TR 54-231 Part 6
ASTIA Document No. AD 155632

June 1958

SUBJECT: DEVELOPMENT OF NONDESTRUCTIVE TESTS FOR STRUCTURAL ADHESIVE BONDS
INVESTIGATOR: J. S. Arnold
CONTRACT: AF 33(616)-3833
CONTRACTOR: Stanford Research Institute
ABSTRACT: An ultrasonic technique for evaluation of structural adhesive bonds (the STUB-meter) is being developed and tested. The operation of the instrument is based on the empirically observed fact that the behavior of a ferroelectric transducer, when mechanically coupled to a test specimen, is affected by the structural properties of the test specimen. An evaluation program has been carried out in cooperation with organizations in the aircraft industry. The results of the program prove the technique to be useful, and do much to define the proper ranges of parameters for its application.

Laboratory work has produced a significant improvement in the description of the electromechanical phenomena of the method, and experimental apparatus has been constructed to take advantage of this information.

TEXTILES

WADC TR 58-30
ASTIA Document No. AD 151133
OTS Release

April 1958

SUBJECT: DEVELOPMENT OF AN OUTER SHELL AND A FUNCTIONAL CLOTHING FABRIC
INVESTIGATOR: Joseph L. Barach
Arthur S. Tingas
CONTRACT: AF 33(600)-32556
CONTRACTOR: Celanese Corporation of America
ABSTRACT: The purpose of this report is to summarize the experimental work performed and the technical data obtained in developing an Outer Shell and a Functional Clothing fabric for Wright Air Development Center. In the course of this program, a large number of experimental fabrics were prepared, dyed, finished, and evaluated. Details of fabric preparation, dyeing and finishing procedures followed, and results obtained are given in this report.

The most difficult problems encountered during this work were those of dyeing the various fiber blends and combinations to match the requested color shade and of finishing the Outer Shell fabrics for combined water repellency and flame retardancy.

Two fabrics were selected as the constructions most closely meeting the requirements. A Dacron/rayon blend for the Functional Clothing fabric and a Fortisan/cotton combination for the Outer Shell fabric. In addition, other constructions of interest were developed such as nylon/Verel, nylon/cotton, nylon/rayon, Fortisan/Dacron, Fortisan/Verel combinations and a nylon/rayon intimate fiber blend.

WADC TR 58-130
ASTIA Document No. AD 206894
OTS Release

November 1958

SUBJECT: DEVELOPMENT OF DURABLE FLAME-RETARDANT FINISHES
FOR COTTON

INVESTIGATOR: John G. Frick, Jr. Ethel K. Leonard
Richard L. Arceneaux J. David Reid

CONTRACT: AF 33(616)-56-59

CONTRACTOR: United States Department of Agriculture

ABSTRACT: New methods for imparting a durable, flame-retardant finish to cotton fabrics were investigated. Primarily, methods were sought for the chemical attachment of phosphorus-containing groups to cellulose. Classes of compounds investigated include: amides of phosphorus (V) acids; imides of phosphorus (V) acids; tetramethylphosphorodiamidic acid derivatives; phosphorus compounds containing epoxy groups; triazinyl-phosphonates; and phosphoroisothiocyanatide derivatives. Also investigated were modifications of the phosphoric acid-urea process for the phosphorylation of cotton. The best finish developed was inferior in some respects to existing finishes. Some suggestions for future work are included.

WADC TR 58-410
ASTIA Document No. AD 206891
OTS Release

December 1958

SUBJECT: DEVELOPMENT OF CORELESS TYPE BRAIDS FOR USE IN
PERSONNEL PARACHUTE SUSPENSION LINES

INVESTIGATOR: Melvin B. Landis
Freeman W. Fraim III

CONTRACT: AF 33(616)-3993

CONTRACTOR: Essex Mills, Incorporated

ABSTRACT: The purpose of this investigation was to develop coreless type braids for use in personnel parachute suspension lines.

Specifically the braids developed were to equal or exceed the specification minimums of strength, weight in yards per pound, and elongation of Type II and Type III cords as made under Specification MIL-C-5040A. The coreless braids developed were to have equal or better seam efficiency, abrasion resistance, snag resistance, and energy absorption than the core and sleeve type cords.

The coreless cords were to be made using both Nylon 6 and Nylon 6,6.

To evaluate snag resistance a machine was developed. To evaluate abrasion resistance a procedure was developed using the abrasion machine described in MIL-W-4088C.

This investigation showed that coreless type cords can be produced to replace the presently used core and sleeve type cords. Within the scope of this project it was not possible to develop coreless cords which were equal or superior to the present core and sleeve cords as to snag resistance. It was found that the snag resistance of several of the coreless braids developed were approximately equal to the Type III although higher than the Type II. In all other requirements, which include abrasion resistance, weight per unit length, energy absorption, breaking strength, elongation, and seam efficiency, the new coreless cords are equal or superior.

Nylon Type 6 coreless cords compared as follows to Nylon 6,6 coreless cords.

Coreless Type 6
Compared To
Coreless Type 6,6

| | |
|---------------------|----|
| Strength | AE |
| Elongation | S |
| Weight - yds./lb. | AE |
| Abrasion Resistance | S |
| Snag Resistance | P |
| Energy Absorption | AE |
| Seam Efficiency | AE |

S -- Superior
P -- Poorer
AE -- Approximately Equal

The following table compares the coreless cords to the core and sleeve type cords they were developed to replace.

| | COMPARED TO TYPE III | | COMPARED TO TYPE II | |
|------------------------|----------------------|----------|---------------------|----------|
| | CORELESS | | CORELESS | |
| | TYPE 6 | TYPE 6,6 | TYPE 6 | TYPE 6,6 |
| Breaking Strength lbs. | S | S | S | S |
| Elongation % | S | S | S | S |
| Abrasion Resistance* | S | P | S | S |
| Snag Resistance* | P | AE | P | P |
| Seam Efficiency %* | S | S | S | S |
| Energy Absorption* | S | S | S | S |
| Weight yds/lb | S | S | S | S |

- S - Superior in that specification minimums were exceeded.
P - Poorer in comparison. No specification requirement.
AE - Approximately equal when compared. No specification requirement.
* - No specification requirements for these tests. The test results S, AE, or P are comparison results only.

WADC TR 58-509
ASTIA Document No. AD 211911
OTS Release

April 1959

SUBJECT: DEVELOPMENT OF IMPROVED NYLON WEBBINGS
INVESTIGATOR: Chauncey C. Chu
Ernest R. Kaswell
Donald J. Doull
CONTRACT: AF 33(600)-34381
CONTRACTOR: Fabric Research Laboratories, Inc.
ABSTRACT: In general, methods of extending the useful service life of Air Force webbings have been limited to resin treatments which improve abrasion resistance. Little attention has thus far been paid to the influences of structural geometry on webbing performance. This project was aimed at a study of these influences.

Thirty-two experimental webbings, woven from nylon type 6 Caprolan yarns, meeting the general dimensional requirements of Specification MIL-W-4088B Type XIII webbing, were designed and constructed. These webbings, containing systematic variations in constructional geometry, were thoroughly evaluated. Results indicate that proper construction can produce a webbing strength increase of approximately 8 percent over the presently specified standard. Using percent strength loss as a criterion, abrasion resistance was appreciably improved since the loss was reduced from 42 percent to 8 percent.

Unfortunately the design for maximum original strength does not coincide with the design for maximum abrasion resistance. Thus the design of an improved webbing must be a compromise between high initial strength and high abrasion resistance.

Six optimum experimental webbing constructions have been proposed, but have not been constructed or evaluated in this program. It is anticipated that three of these will have higher original strengths, higher abrasion resistances, and equal weights, as compared with the present Type XIII standard. The other three should exceed the minimum strength requirements, have significantly improved abrasion resistance, and at least a 20 percent reduction in weight.

TRANSPARENT MATERIALS

WADC TR 56-557 Part II
ASTIA Document No. AD 155580

May 1958

SUBJECT: EFFECTS OF GAMMA RADIATION ON AIRCRAFT
TRANSPARENT MATERIALS
INVESTIGATOR: Donald L. Schmidt
ABSTRACT: This report presents additional data on gamma radiation-induced changes in commonly-used and experimental transparent plastic materials.

Eight materials of an acrylic or polyester type were irradiated to maximum absorbed energy levels of 10^6 to 10^{10} ergs per gram in a cobalt-60 isotope facility. The irradiated materials were then evaluated in accordance with standard testing procedures to determine (a) which physical properties were altered by gamma irradiation, (b) the nature of these changes, and (c) the magnitude of these changes.

Results of this investigation show that most of the plastic materials properties were affected by a high intensity gamma radiation environment. The principal effect was found to be that of degradation, but initial property improvements were also noted. This latter effect, however, was almost always followed by degradation upon continued irradiation.

Comparative radiation stability data are presented on the various irradiated transparent plastic materials. Threshold and 25 percent damage dosages for the individual materials properties are reported. The optical properties of the materials were more susceptible to gamma radiation than were the mechanical, thermal or permanence-type properties. Threshold dosages were about 1 to 5×10^7 ergs per gram for optical properties that change with irradiation, and about 10^8 to 10^9 ergs per gram for other radio-sensitive properties.

WADC TR 57-213 Part II
ASTIA Document No. AD 155803

August 1958

SUBJECT: SILICONE INTERLAYER PROGRAM

INVESTIGATOR: Keith E. Polmanteer
Francis J. Campbell
Thomas L. Laur

CONTRACT: AF 33(600)-34984

CONTRACTOR: Dow Corning Corporation

ABSTRACT: The main objective during the contract was to improve Type M interlayer or to develop a subsequent material to eliminate the need for capillaries in Type M laminates. A number of modifications of Type M interlayer were tested but none of these had all the requirements to make them better than Type M. One modification, which had greater thermal stability than Type M, was not self-adhering to glass or aluminum. A number of adhesive materials were tried in conjunction with this modification, but none were satisfactory. However, properties of several of these materials were encouraging. Development work will continue.

A study was made of the temperature gradients existing in Type K laminates when subjected to simulated flight conditions. This study pointed out the effect of glass thickness on the relation between the surface temperatures of the laminate and the peak interlayer temperature.

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| <p>WRIGHT AIR DEVELOPMENT CENTER, MATERIALS LABORATORY, WPAFB, OHIO - A REVIEW OF THE AIR FORCE MATERIALS RESEARCH AND DEVELOPMENT PROGRAM, by Mrs. H. Maxwell. July 1959 163p. (WADC TR 53-373 Sup 6)</p> <p>Unclassified report</p> <p>Two hundred and twelve (212) technical reports and technical notes written during the period 1 July 1958 - 30 June 1959 are abstracted herein. These reports cover the following general areas of research: adhesives, biochemistry, electronic materials, materials physics, metallurgy, petroleum products, plastics, protective treatments, rubber and textiles.</p> | <p>UNCLASSIFIED</p> | <p>UNCLASSIFIED</p> |
| <p>(over)</p> <p>A numerical index, contractor index and an investigator index of all the technical reports and technical notes issued during the period March 1923 - June 1959 are also provided.</p> | <p>UNCLASSIFIED</p> | <p>UNCLASSIFIED</p> |
| <p>UNCLASSIFIED</p> | <p>UNCLASSIFIED</p> | <p>UNCLASSIFIED</p> |